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Military Facilities Engineering Technology

Facility Energy Performance Benchmarking in a Data-Scarce Environment

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Abstract

Current federal, Department of Defense (DoD), and Army energy-efficiency goals require a proactive approach to investment, building operations, and energy savings. Much responsibility for meeting these requirements is assigned to Army installation staff, who often have difficulties identifying and interpreting the applicable mandates. To address this problem, the research group began work to develop an intelligent framework that describes and clarifies interrelationships among energy efficiency, component maintenance and renewal, and mission requirements to support an integrated investment strategy that minimizes total cost of ownership (TCO). The main thrusts of the study were to develop integrated investment decision models, identify DoD facility Energy Use Intensity (EUI) benchmarks in a data-scarce environment, and analyze occupant-, system-, and component-level faults contributing to energy inefficiency.

A methodology for developing DoD-specific facility EUIs will serve as a decision framework for actions involving buildings with the highest EUIs. Thus, Army-specific benchmarking results will support more cost-effective component-renewal investment strategies. Altering the timing and grouping of investments can improve the energy efficiency to lower the TCO throughout the facility life cycle. This research will help the Army more effectively implement energy improvements to meet and exceed energy-efficiency requirements.

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Preface

This study was conducted for Headquarters, U.S. Army Corps of Engineers under Program Element 622784T41, “Military Facilities Engineering Technology”; Project P2 370256, “High Performance Building Operations–Decision Analysis for Energy (FY12–15).” The technical monitor was Kurt Kinnevan, CEERD-CZT.

The work was performed by the Energy Branch of the Facilities Division (CEERD-CFM), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Dr. Andrew J. Nelson was Chief, CEERD-CFE; Donald K. Hicks was Chief, CEERD-CF; and Kurt Kinnevan was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti and the Director was Dr. Ilker Adiguzel.

The Commander of ERDC was COL Bryan S. Green and the Director was Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
kWh	0.001	Watt-hour
MWh	0.001	kWh
kBTUh	0.001	BTUh
BTUh	3412.142	kWh
kBTUh	3.412142	kWh
BTUh	1028 (varies)	cfh
kW	29.3	Therm
cf	96.7 (often rounded to100)	Therm
BTU	100,000	Therm
kBTU	100	Therm
BTU	1 mil	MBTU [or MmBTU if using Roman Numerals]
Days	28.2422	February

1 Introduction

1.1 Background

Current federal government, Department of Defense (DoD), and Army energy-utilization mandates require a proactive approach to military infrastructure investment, building operations, and energy efficiency. Implementing these mandates and achieving DoD objectives is a responsibility shared at many levels, including Army facility management personnel. Meeting the DoD and Army goals requires a highly complex and coordinated effort that could greatly benefit from the application of improved methods and automated analysis tools.

The U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) was funded through the Army Research, Development, Test, and Evaluation (RDTE) Program to develop an intelligent framework, encompassing methodology and modeling, that describes interrelationships between energy efficiency, facility component maintenance and renewal, and mission requirements. The purpose of this framework is to facilitate the development of an integrated infrastructure investment strategy that minimizes facility total cost of ownership (TCO). A critical part of this research, and also for managers tasked with reducing energy utilization and costs, is the capability to create and apply Energy Use Intensity (EUI) benchmarks for DoD facilities. EUI represents the energy per square foot per year used by a building.

Energy utilization and cost benchmarking are very difficult for the Army because less than 0.1% of facilities are connected to the Meter Data Management System (MDMS), a central energy-reporting system operated by Huntsville District. Although the problem of energy cost and utilization data scarcity will be mitigated with the further deployment of the MDMS and policies that mandate meter deployment recently established by the Assistant Secretary of the Army (Installations, Energy and Environment), there are currently no models that accurately indicate valid EUIs for different types of Army facilities.

Commercially available benchmarks, such as the Commercial Building Energy Consumption Survey (CBECS), do not accurately capture the different types of Army facility missions, characteristics (age, construction type,

etc.), or dynamic demand factors (troop deployment, reserve drills, etc.). In general, such benchmarking systems cannot be used by MDMS or Army managers to analyze facility consumption trends and identify poor energy performers by installation, climate zone, and other criteria.

A methodology for creating the DoD-specific EUIs would be an important part of a decision framework for applying corrective actions to facilities with the highest EUIs. Army-specific benchmarking results would allow the most effective component-renewal investment strategies by targeting the most inefficient facilities. Optimizing the timing and grouping of investments can significantly improve Army energy efficiency and reduce the TCO throughout the facility life cycle. The results of this research will help the Army to more effectively implement energy improvements, meeting or exceeding DoD energy-efficiency requirements.

1.2 Objectives

The objectives of this project were to

- develop integrated investment decision models
- identify EUI benchmarks that are applicable in the data-scarce Army facility-management practice
- detect and diagnose occupant-, system-, and component-level faults contributing to high facility EUIs.

1.3 Approach

This work addressed the development of benchmark EUIs for selected building types used on installations in the continental United States. Development of algorithms for optimizing the TCO of Army facilities focused on operational methods and requirements unique to the Army environment.

The research team evaluated data from the MDMS to understand Army-wide energy consumption patterns and analyze detailed facility utility consumption data. In terms of energy consumption, the top three facilities across the Army were (1) barracks, (2) general administrative buildings, and (3) vehicle maintenance facilities. The available MDMS data for these facility types were analyzed to create benchmark EUIs for DoD-specific buildings.

1.4 Scope

The text of this report may imply an assumption that installation personnel are familiar with all applicable energy use and reporting requirements, and how those requirements pertain to a wider variety of facilities. However, the authors acknowledge that installation personnel often have difficulties researching and identifying the applicability of government requirements to specific installations, facilities, and utilization cases due to competing priorities and other factors. The research team addresses this problem in a related ERDC/CERL Special Report (SR) by compiling abstracts for all applicable federal, DoD, and Army requirements and implementation guidance pertaining to facility energy metering and benchmarking. That document is published concurrently as ERDC/CERL SR-17-13 (Josefik et al. 2017).

2 Meter Data Reporting Systems

Building energy conservation efforts begin with having energy data to benchmark. Until relatively recently, DoD and the Army only had access to installation-level (also known as *at-the-gate*) energy-consumption data through the Defense Utility Energy Reporting System (DUERS) and Army Energy and Water Reporting System (AEWRS) systems. While these data were useful to a degree, it quickly became apparent that building-level data were required to determine the true nature of energy consumption within Army installations. Therefore, individual installations began installing meters and recording energy consumption at the building rather than at the gate. The sporadic nature of this effort, however, limited its usefulness as well. The MDMS sought to standardize the installation of these building energy meters in order to better understand Army-wide energy consumption patterns.

2.1 Installation-level metering

2.1.1 Defense Utility Energy Reporting System (DUERS)

Military installations report monthly installation-level energy use in the DUERS. The DUERS is an automated management information system with which DoD monitors its supplies and consumption of energy. It was originally fielded in February 1974 as the Defense Energy Information System (DEIS) to respond to the need to manage DoD energy resources more closely in the aftermath of the 1973 oil crisis. It is primarily used as an energy management tool, providing information about the DoD inventory and consumption of utility energy. The DUERS is used to (1) help formulate energy policy; (2) prepare management reports; (3) measure energy conservation achievements and determine progress toward energy goals and targets; (4) report energy data to Congress and other federal agencies; (5) provide online access to DoD energy data for all valid users; (6) identify energy usage and consumption trends; (7) ensure that all DoD components meet system reporting requirements; and (8) download and export energy data to automated systems for local, regional, and global analysis.[1]

[1] DoD 5126-46-M-2, *Defense Utility Energy Reporting System*, November 1993, p 1-1.

2.1.2 Army Energy and Water Reporting System (AEWRS)

All Army data submitted to DUERS is input by installations through the AEWRS.[2] This system is designed to facilitate energy management by providing timely, reliable, and accurate information on Army energy use. It provides essential energy management information to installations, regions, Major Subordinate Commands (MSCs), major Army Commands (MACOMs), Department of the Army (DA), and DoD (through DUERS). This information is used to evaluate energy trends and to determine progress toward energy use reduction goals and targets.[3]

2.2 Whole-building metering

2.2.1 Meter Data Management System (MDMS)

While DUERS and AWERS sought to record installation-level energy consumption, the Army Metering Program's MDMS has increased data fidelity by tracking building specific energy usage. For the past decade Army installations have been installing energy meters on their facilities in order to satisfy the energy conservation mandates discussed previously. These metering efforts, however, lacked consistency across facilities, installations, and commands. Therefore, in Fiscal Year (FY) 2007, MDMS was proposed as a means to standardize utility monitoring across all Army facilities. The FY 2008 work plan included the installation of advanced electric and natural gas meters at 22 Army installations within the continental United States and award of the MDMS software development and support contract.[4] Out-year efforts include metering program expansion to 43 installations, then to 100 more, and eventually to all installations worldwide.[5]

Army EXORD-028-12, dated November 2011, designated the U.S. Army Engineering and Support Center, Huntsville, Alabama (CEHNC) as the primary developer of the MDMS system. CEHNC has designed MDMS to

[2] The Air Force reports via the Air Force Energy Reporting System (AFERS) and the Navy reports via the Maximo Circuits system.

[3] ODUSD/I&E, *Department of Defense Energy Manager's Handbook*, p 43.

[4] Public Works Digest, *Huntsville Center Projects Range from Saving Energy to Designing State-of-the-Art Facilities*, November/December 2007, p 11.

[5] *Advanced Metering Solutions for Federal Agencies* Meeting Report, 7 December 2010. Washington Convention Center.

be a secure means of collecting and analyzing metered energy data at installations. It is programmed to present the information in a graphical, web-accessed dashboard to enable rapid identification and response to energy related situations. Installation data sent to the web-based enterprise system can be used for near-real-time viewing, normalization, and analysis by installation energy managers. MDMS is intended to help them (1) manage and control installation-level energy consumption and demand, (2) act on energy-use anomalies, and (3) identify energy-saving opportunities.

At the agency level, MDMS gives the Army the data to leverage successful energy strategies across the service and highlight areas for improvement. Development of algorithms for energy use analysis using MDMS data is a primary objective of this research. The reporting status of the MDMS metering program is shown in Table 1.[6]

[6] Although MDMS was set up to retrieve meter data from Fort Leonard Wood, installation infrastructure was not yet available. For that reason, their meter data were acquired directly from the installation.

Table 1. MDMS metering program status as of 18 September 2015.

Organization	Metered Buildings	Electric Meters	Gas Meters	Water Meters	Data Interval	Fully Operational?
IMCOM	**5020**	**7705**	**843**	**751**		
ATLANTIC REGION	**2297**	**3790**	**371**	**681**		
ABERDEEN PROVING GROUND	113	241	0	0	15 min	X
ADELPHI LABORATORY CENTER	14	106	3	0	15 min	X
CARLISLE BARRACKS	21	25	23	0	15 min	X
FORT A P HILL	6	6	0	0	15 min	X
FORT BELVOIR	252	787	0	0	30 min	
FORT BENNING	797	1387	0	0	1 hr	
FORT BRAGG	589	496	207	678	15 min	X
FORT CAMPBELL	27	29	0	0	15 min	X
FORT DETRICK	0	0	0	0	15 min	
FORT DRUM	0	0	0	0	15 min	
FORT GILLEM	7	8	8	0	15 min	X
FORT GORDON	0	0	0	0	15 min	
FORT HAMILTON	0	0	0	0	15 min	
FORT JACKSON	39	50	11	0	15 min	X
FORT KNOX	0	0	0	0	15 min	
FORT MCNAIR	7	10	6	0	15 min	X
FORT MYER	11	11	6	0	15 min	X
FORT RUCKER	29	36	21	0	15 min	X
FORT STEWART	135	245	54	3	15 min	
NATICK SSC	37	49	0	0	15 min	X
PICATINNY ARSENAL	98	153	0	0	1 hr	
REDSTONE ARSENAL	47	66	0	0	15 min	X
TOBYHANNA ARMY DEPOT	19	25	0	0	15 min	X
WATERVLIET ARSENAL	0	0	0	0	15 min	
WEST POINT	49	60	32	0	15 min	
CENTRAL REGION	**2054**	**3039**	**472**	**70**		
DETROIT ARSENAL	16	35	7	0	15 min	X
DUGWAY PROVING GROUND	19	24	0	0	15 min	X
FORT BLISS	188	244	124	67	15 min	
FORT CARSON	268	255	218	3	15 min	
FORT HUACHUCA	1316	2133	0	0	1 hr	
FORT IRWIN	37	40	0	0	15 min	X
FORT LEAVENWORTH	0	0	0	0	15 min	
FORT LEONARD WOOD	0	0	0	0	15 min	
FORT POLK	26	26	7	0	15 min	X
FORT RILEY	0	0	0	0	15 min	
FORT SILL	0	0	0	0	15 min	
JOINT BASE LEWIS-MCCHORD	74	111	93	0	15 min	X
PRESIDIO OF MONTEREY	47	54	0	0	15 min	X
ROCK ISLAND ARSENAL	30	77	23	0	15 min	X
WHITE SANDS MISSILE RANGE	7	7	0	0	15 min	
YAKIMA TRAINING CENTER	0	0	0	0	15 min	
YUMA PROVING GROUND	26	33	0	0	15 min	X
EUROPE REGION	**510**	**681**	**0**	**0**		
USAG BAUMHOLDER	127	131	0	0	15 min	
USAG BAVARIA	58	64	0	0	15 min	
USAG BENELUX	9	11	0	0	15 min	
USAG HEIDELBERG	4	4	0	0	15 min	X
USAG HOHENFELS	20	23	0	0	15 min	X
USAG KAISERSLAUTERN	165	253	0	0	15 min	X
USAG LIVORNO	49	63	0	0	15 min	X
USAG STUTTGART	61	110	0	0	15 min	X
USAG WIESBADEN	17	22	0	0	15 min	
PACIFIC REGION	**159**	**195**	**0**	**0**		
FORT SHAFTER	20	26	0	0	15 min	X
SCHOFIELD BARRACKS	139	169	0	0	15 min	X

The MDMS export files include information on location, building use, square footage, meter name, energy commodity type, timestamp, raw meter reading, units, power factor, peak demand, and average demand as shown in Table 2.

Table 2. Sample MDMS export.

Site	Building	SF	Meter	Commodity	Timestamp	Raw reading	Units	Power factor(%)	Peak demand	Avg demand
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 00:00	2055972.63	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 00:15	2056007.38	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 00:30	2056029.13	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 00:45	2056051.63	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 01:00	2056086.63	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 01:15	2056125.00	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 01:30	2056159.88	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 01:45	2056193.88	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 02:00	2056230.00	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 02:15	2056252.38	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 02:30	2056276.25	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 02:45	2056302.00	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 03:00	2056323.75	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 03:15	2056345.50	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 03:30	2056368.38	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 03:45	2056390.13	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 04:00	2056412.88	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 04:15	2056436.00	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 04:30	2056455.63	kWh	NA	NA	NA
FORT SAMPLE	1234 ENLIST UPH	123,860	SAMP_BLDG_1234	Electricity	2012-09-23 04:45	2056478.75	kWh	NA	NA	NA

2.2.2 Commercial utility meters

Energy meters used by private-sector utility companies and cooperatives measure data more comprehensively than those connected to the MDMS system. This is done so these businesses can balance energy production with public demand and so they can generate revenue. Private-sector utility meters typically generate reports similar to the one shown in Table 3, with metrics for revenue, demand, power, and voltage.

Table 3. Example report generated by a private utility provider.

	Revenue									Demand		Power	Voltage			
Timestamp	kWh del int	kVARh del int	kWh rec int	kVARh rec int	Water int	Gas int	Steam int	kWh rec	kW sd del	kWh del	kW sd mx del	PF Avg	V1 THD avg	Vln avg	I avg	I1 Phasor Angle
11/16/2011@13:45:00.000	45.49	13.84	0.00	0.00	0.00	0.00	0.00	0.00	92.66	179,514.64	92.66	-95.59	1.55	268.96	118.61	-22.77
11/16/2011@14:00:00.000	24.14	6.63	0.00	0.00	0.00	0.00	0.00	0.00	96.59	179,538.78	96.59	-96.40	1.58	273.80	122.67	-20.65
11/16/2011@14:15:00.000	24.02	7.13	0.00	0.00	0.00	0.00	0.00	0.00	96.12	179,562.81	96.59	-95.86	1.61	273.92	122.78	-21.64
11/16/2011@14:30:00.000	23.50	6.64	0.00	0.00	0.00	0.00	0.00	0.00	94.01	179,586.30	96.59	-96.23	1.61	274.12	119.52	-20.42
11/16/2011@14:45:00.000	25.18	8.43	0.00	0.00	0.00	0.00	0.00	0.00	100.77	179,611.48	100.77	-94.85	1.59	273.86	130.09	-22.91
11/16/2011@15:00:00.000	23.50	7.27	0.00	0.00	0.00	0.00	0.00	0.00	94.02	179,634.98	100.77	-95.54	1.59	274.09	120.48	-22.08
11/16/2011@15:15:00.000	22.67	6.68	0.00	0.00	0.00	0.00	0.00	0.00	90.71	179,657.66	100.77	-95.92	1.60	274.64	115.47	-20.85
11/16/2011@15:30:00.000	22.59	7.00	0.00	0.00	0.00	0.00	0.00	0.00	90.35	179,680.25	100.77	-95.52	1.59	274.94	115.40	-21.74
11/16/2011@15:45:00.000	23.00	7.46	0.00	0.00	0.00	0.00	0.00	0.00	92.00	179,703.25	100.77	-95.14	1.57	275.16	117.93	-22.67
11/16/2011@16:00:00.000	22.22	7.08	0.00	0.00	0.00	0.00	0.00	0.00	88.91	179,725.47	100.77	-95.28	1.62	275.51	113.66	-22.63
11/16/2011@16:15:00.000	21.19	6.88	0.00	0.00	0.00	0.00	0.00	0.00	84.77	179,746.66	100.77	-95.09	1.66	275.70	108.52	-23.21
11/16/2011@16:30:00.000	20.48	6.83	0.00	0.00	0.00	0.00	0.00	0.00	81.92	179,767.13	100.77	-94.87	1.55	275.48	105.10	-22.18
11/16/2011@16:45:00.000	18.85	7.37	0.00	0.00	0.00	0.00	0.00	0.00	75.39	179,785.97	100.77	-93.10	1.51	274.94	98.65	-23.91
11/16/2011@17:00:00.000	17.06	7.09	0.00	0.00	0.00	0.00	0.00	0.00	68.24	179,803.03	100.77	-92.30	1.55	273.85	90.56	-25.56
11/16/2011@17:15:00.000	16.09	4.23	0.00	0.00	0.00	0.00	0.00	0.00	64.38	179,819.13	100.77	-96.69	1.58	273.07	81.94	-18.63
11/16/2011@17:30:00.000	15.19	4.16	0.00	0.00	0.00	0.00	0.00	0.00	60.77	179,834.31	100.77	-96.40	1.57	273.75	77.42	-19.07
11/16/2011@17:45:00.000	13.28	3.56	0.00	0.00	0.00	0.00	0.00	0.00	53.15	179,847.59	100.77	-96.58	1.60	274.48	67.65	-20.96
11/16/2011@18:00:00.000	12.33	3.56	0.00	0.00	0.00	0.00	0.00	0.00	49.35	179,859.92	100.77	-96.07	1.61	276.17	62.90	-23.77
11/16/2011@18:15:00.000	12.15	3.69	0.00	0.00	0.00	0.00	0.00	0.00	48.64	179,872.08	100.77	-95.67	1.55	276.07	62.28	-24.50
11/16/2011@18:30:00.000	12.03	3.67	0.00	0.00	0.00	0.00	0.00	0.00	48.16	179,884.11	100.77	-95.65	1.54	276.17	61.66	-24.23

3 Building Selections

3.1 Priority Army building types

A critical component of this study was the availability of detailed utility consumption data. Because Army policy requires utility metering of all buildings greater than 29,000 ft^2, it was assumed that such large buildings would yield the greatest amount of usable data.[7] Of those buildings 29,000 ft^2 and greater, the top three in combined floor area are (1) barracks, (2) general administrative buildings, and (3) vehicle maintenance facilities.

Having found the largest building types, it was quickly determined that barracks and vehicle maintenance facilities should be prioritized for their quantity and overall footprint. General administrative buildings, however, were determined to be too similar to their commercial counterparts to provide DoD-specific results. In their place, dining facilities were chosen. These buildings were generally above the 29,000 ft^2 threshold, and it was hypothesized that dining facilities would have higher EUIs than other building types above 29,000 ft^2 in size.

Table 4. 3Q FY15 Barracks statistics in the Army real property database.

Total Floor Area (ft^2)	Quantity (Q3 FY15)	CATCODE	Description
7,448,548	97	72010	Transient Lodging
53,336,692	978	72111	Enlisted Unaccompanied Personnel Housing
2,401,052	27	72112	Unaccompanied Housing for Wounded Warriors
4,948,617	121	72114	Annual Training/Mobilization Barracks (TT/ENL)
301,284	7	72115	Annual Training/Mobilization Barracks (MOB ENL BRKS)
5,653,690	82	72121	Student Barracks (TRANS UPH/AIT)
3,258,300	60	72122	Student Barracks (TRANS UPH/AST)
917,580	21	72170	Enlisted Unaccompanied Personnel Housing (UPH SR NCO)
9,423,078	145	72181	Recruit/Trainee Barracks
1,693,337	38	72410	Officer Unaccompanied Personnel Housing
89,382,178	**1,576**	**Total**	

7 Valine, Debra, "Corps of Engineers helps Army installations reduce energy use, save money", USACE Huntsville Center, August 31, 2009, http://www.army.mil/mobile/article/?p=26770

Table 5. 3QFY15 Vehicle maintenance shop statistics in the Army real property database.

Total Floor Area (ft^2)	Quantity (Q3 FY15)	CATCODE	Description
1,801,249	41	21407	Vehicle Maintenance Shop, National Guard (ARNG VEH MAINT)
497,208	13	21409	Vehicle Maintenance Shop, Reserve (USAR VEH MAINT)
10,310,212	226	21410	Vehicle Maintenance Shop
142,969	3	21412	Vehicle Maintenance Shop (MAINT STORAGE)
135,104	3	21414	Vehicle Maintenance Shop (GEN ITEM REPAIR)
30,084	1	21416	Vehicle Maintenance Shop (MSL MAINT FAC)
103,881	2	21417	Vehicle Maintenance Shop (VEH PNT/PREP SH)
408,273	10	21418	Vehicle Maintenance Shop, Reserve (AMSA/ECS)
5,346,017	78	21419	Vehicle Maintenance Shop, National Guard (CSMS/MATES)
2,044,397	24	21435	Vehicle Maintenance Shop, Depot (MAJ END ITM REB)
2,407,568	25	21440	Vehicle Maintenance Shop, Depot (COMP REB DEPOT)
23,226,962	**426**	**Total**	

Table 6. 3QFY15 Dining facility statistics in the Army Real Property database.

Total Floor Area (ft^2)	Quantity (Q3 FY15)	CATCODE	Description
1,360,446	30	72210	Dining Facility
67,791	2	72212	Dining Facility
1,428,237	**32**	**Total**	

3.2 Building attributes

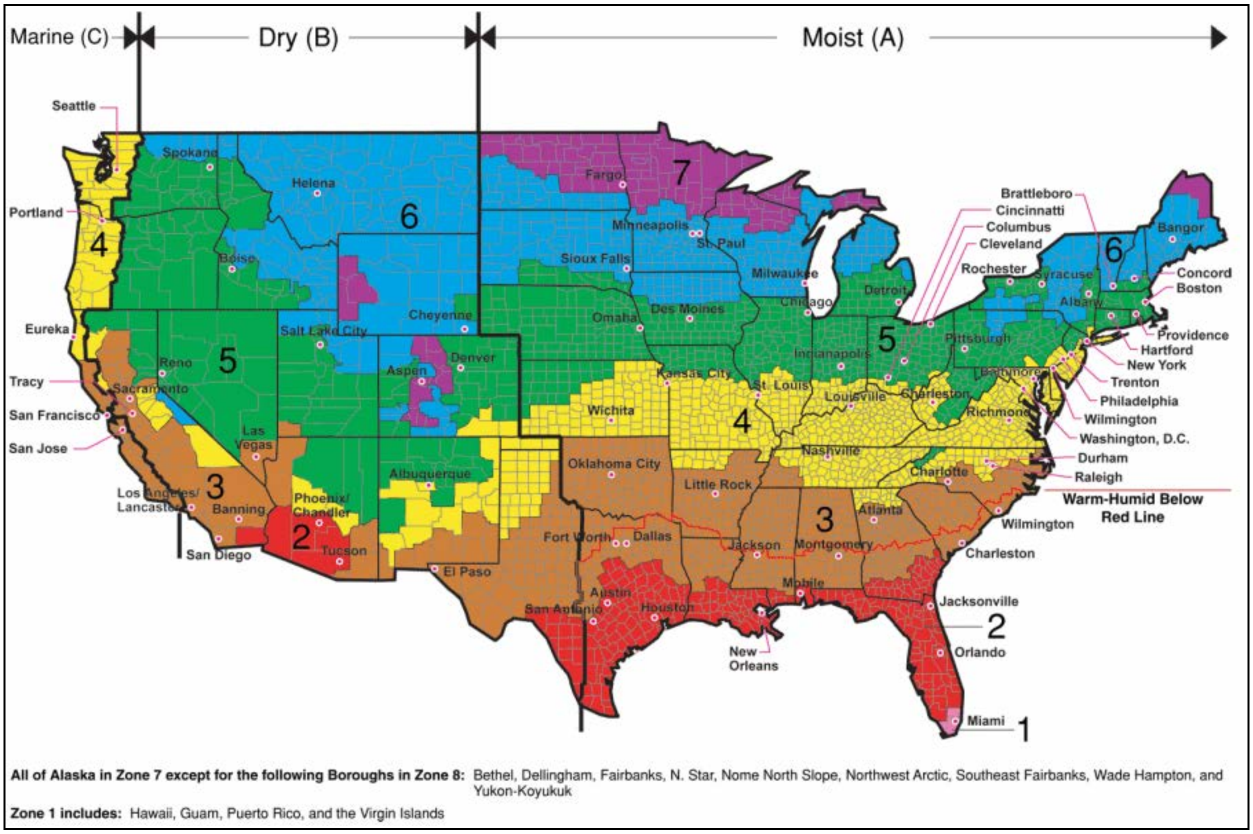
3.2.1 EISA-required building attributes

Energy Independence and Security Act (EISA), Section 432 IIC, specifies the minimum number of building attributes to be used in energy benchmarking. These attributes allow for reasonable comparisons between similar buildings:

- Building name or identifier
- Building type according to use
- Building location by climate zone [8] or zip code (see Figure 1)
- Floor area (gross square feet)

[8] International Code Council, International Energy Conservation Code (IECC), 2000.

Figure 1. International Energy Conservation Code (IECC) climate zone map.



Since more attributes tend to yield increasingly more accurate benchmarks, additional attributes from the Army real property database were considered (see section 3.2.2).

3.2.2 Building attributes in Army's HQIIS

The Headquarters Installation Information System (HQIIS) is the official registry of Army installations and sites, and the data warehouse for Army real property and related information. The system interfaces with the DoD real property asset registry for statutory and regulatory real property reporting. The primary source systems from which HQIIS receives real property data are:

- GFEBS (General Fund Enterprise Business System),
- PRIDE (Planning Resource Infrastructure Development and Evaluation System),
- RFMIS (Rental Facility Management Information System), and
- REMIS (Real Estate Management Information System).

The project-relevant building attributes represented by data fields in HQIIS are shown in Table 7.

Table 7. Energy-relevant building attributes in HQIIS.

Installation name	Foundation construction material
Facility number	Structural construction material
Facility name	Roof construction material
Built date	Floor construction material
Current category code/description	Wall construction material
Design use category code/description	Heating type
Special quantities (meals served, beds, etc.)	Heating fuel
Total area	Cooling type
Floors below ground	Air circulation type
Floors above ground	Advanced electric meter
Floor-to-ceiling height	Advanced gas meter
Construction material	Advanced water meter

In HQIIS, each of the attributes above is linked to a pick list from which to select an input to associate with a facility. The attribute inputs are used in the benchmarking process so system limits to attribute input choices can curtail benchmarking activities. For example, HQIIS does not track window-to-wall ratios, assembly U-Factors, the presence or absence of sustainability features (e.g., cool roofs), and emerging energy technologies (e.g. wind, hydrogen, or geothermal power), all of which are useful for a thorough benchmarking analysis. While this analysis is complete and utilizes all the available data, with these additional attributes, the benchmarks could have been even more accurate.

3.2.3 DoD data analytics and integration support requirements

DoD is subject to extensive energy reporting requirements that impose a growing burden on DoD personnel to collect, analyze, package, and transmit energy data. DoD currently does not have standardized enterprise facility energy information, nor does it have enterprise-wide information technology systems to support facility energy management. This lack of standardization requires energy managers and other personnel to manually collect, transform, and reformat data to meet separate data calls. This situation greatly reduces efficiency and leaves energy managers with little

time to manage facility energy consumption, or to focus on ways to improve facility energy efficiency.

The Data Analytics and Integration Support (DAIS) platform supports OSD (I&E) Business Enterprise Integration office Real Property Inventory Reporting (RPIR) and Enterprise Energy Information Management (EEIM) requirements. EEIM building attributes are being established based on those used by ENERGY STAR® Portfolio Manager.

For comparison, available Army and DoD building attributes can be evaluated against those used by ENERGY STAR® Portfolio Manager (Table 8).

Table 8. EPA Portfolio Manager building attributes by facility type (EEIM).

Required Information	Facility Type									
	Office	Education	Food Sales	Mercantile	Warehouse & Storage	Lodging - Residential	Lodging - Hoteling	Hospital	Religious Worship	Parking
Gross Square Feet	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Weekly Operating Hours	✓		✓	✓	✓				✓	✓
No. of workers on main shift	✓		✓	✓	✓		✓			
No. of personal computers/registers	✓	✓		✓					✓	
% of floor area airconditioned (>=50%, <50%, or none)	✓									
% of floor area heated (>=50%, <50%, or none)	✓									
No. of licensed beds								✓		
No. of floors						✓		✓		
Tertiary care facility (yes/no)								✓		
Lab on-site (yes/no)								✓		
Laundry facilities on-site (yes/no)								✓		
No. of buildings								✓		
On-site cooking (yes/no)		✓	✓				✓		✓	
No. walk-in refrigeration/freezer units		✓	✓	✓			✓		✓	
% of floor area cooled in 10% increments (10%, 20%, 30%,etc.)		✓	✓	✓	✓	✓	✓			
% of floor area heated in 10% increments (10%, 20%, 30%,etc.)		✓	✓	✓	✓	✓	✓			
# open or closed refrigeration/freezer cases			✓	✓						
Days of operation		✓							✓	
High School (yes/no)		✓								
Months of use		✓								
Maximum seating capacity									✓	
No. of units						✓				
No. of bedrooms						✓				
No. laundry hookups in each unit						✓				
No of diswashers in each unit						✓				
Affordable or market rate						✓				
Hrs/day guests on-site							✓			
No guest meals served							✓			
Sq ft - full service spas							✓			
Sq ft - gym/fitness center							✓			
Annual qty of laundry processed on-site							✓			
Average occupancy (%)							✓			
Gross Square Feet enclosed										✓
Gross Square Feet not enclosed with roof										✓
Gross Square Feet open										✓

4 Analysis and Results

4.1 Data collection

This study sought to establish benchmark energy usage intensities for certain building types within domestic army installations. Specifically, barracks, dining facilities (DFACs), and vehicle maintenance (Veh. Maint) buildings were analyzed. The data were primarily obtained using the MDMS database. However, data for all buildings in American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Climate Zone 4A were obtained directly from the utility provider.

After scouring the MDMS database and utility data for all buildings of the desired types at installations throughout the country, 115 examples were found. From these initial 115 buildings, 71 were determined to be acceptable candidates for this study. The remaining 44 buildings were eliminated from the final analysis due to the following factors:

- Lack of one continuous year's worth of data
- Intermittent data
- Missing either gas or electric data
- Obvious errors in MDMS data
- Questionable validity of data

The building type composition of the 71 analyzed buildings can be seen in Figure 2, the location of the analyzed buildings can be seen in Figure 3, and the construction types can be seen in Figure 4. These buildings ranged between 254,000 ft^2 and 6,435 ft^2 and were built between 1927 and 2012. A detailed breakdown by attribute of each building can be found in Table A1, Table A2, and Table A3 in the Appendix.

Figure 2. Building use types.

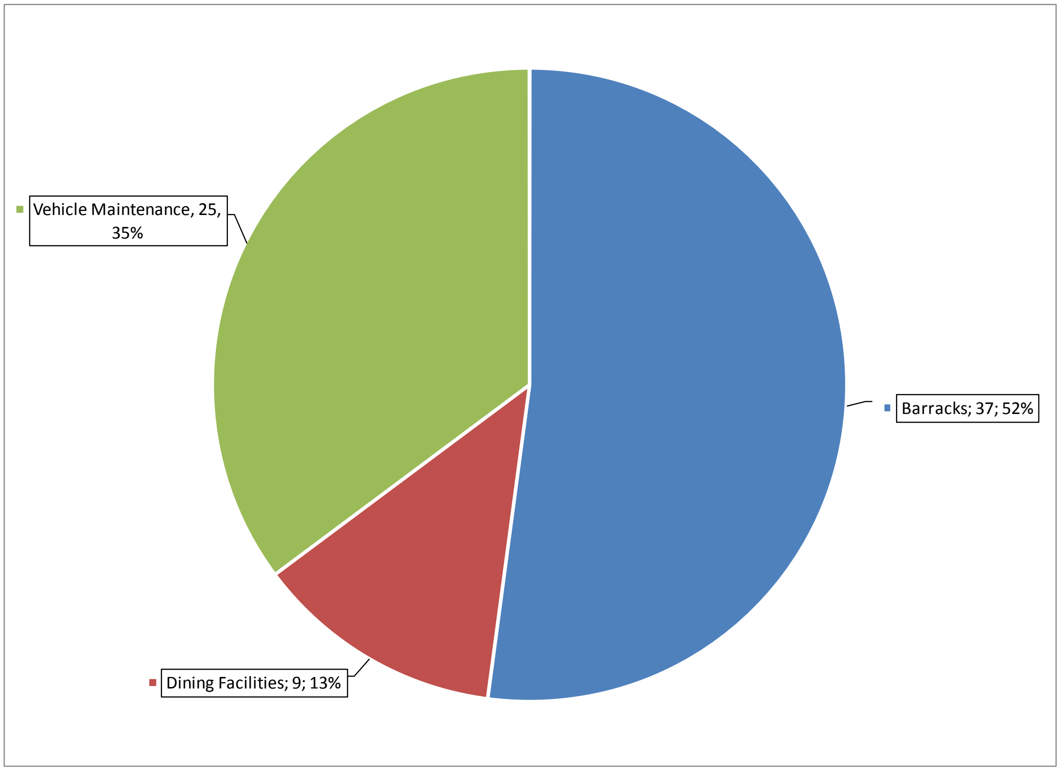


Figure 3. Building climate zone locations.

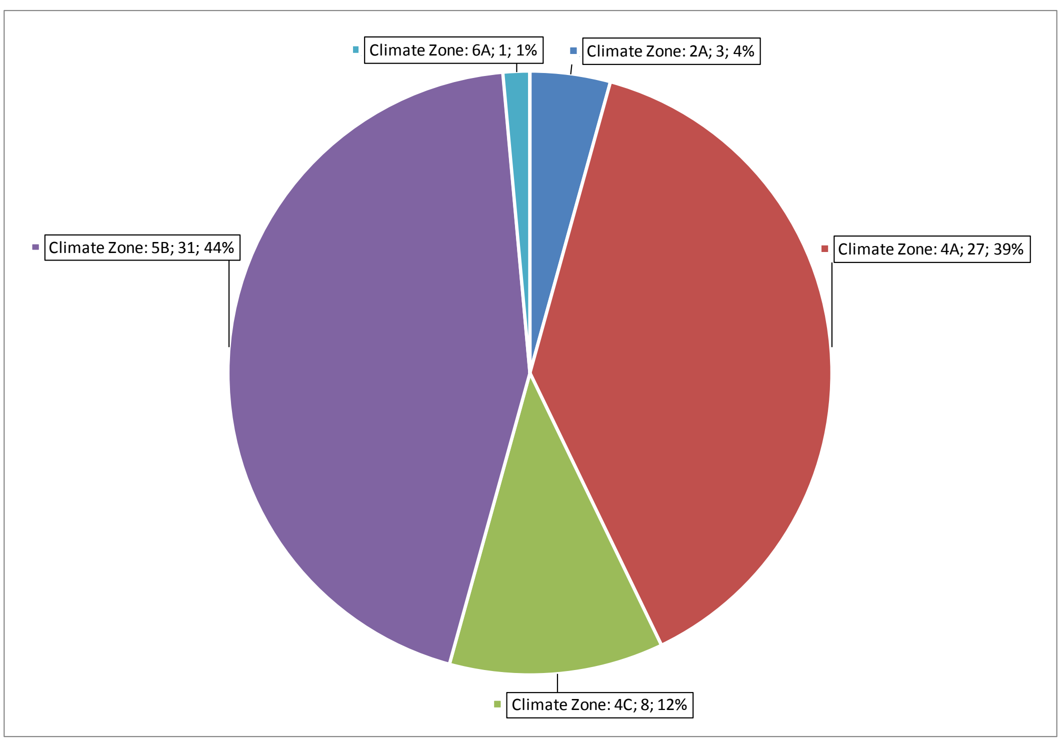
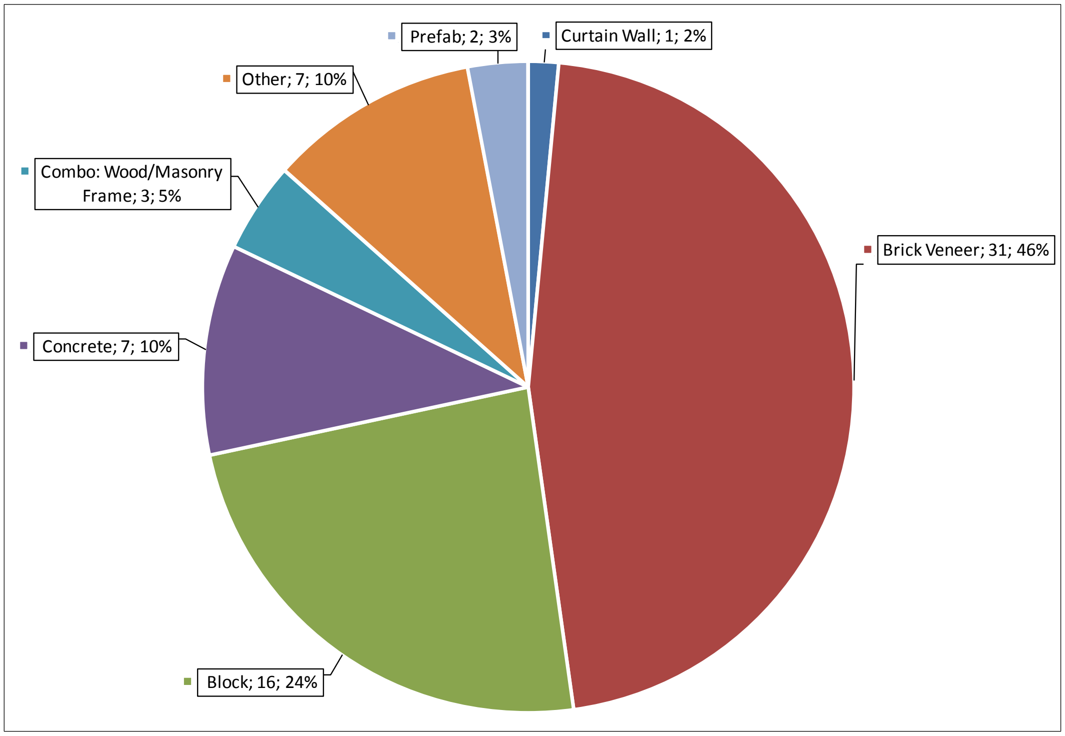


Figure 4. Building construction types.



4.2 Insufficient data

Data scarcity proved to be the primary challenge for establishing the desired benchmarks. As stated above, MDMS was the main source for the analyzed data. The database was queried for barracks, vehicle maintenance buildings, and dining facilities using gas and/or electric fuel sources with data recorded in 15-minute increments. With such high resolution data, it should have been possible to establish accurate and detailed energy profiles.

Unfortunately, due to technological and logistical challenges, the MDMS database remains sparsely populated. Many buildings and installations do not yet have the equipment or manpower to comply with the MDMS standard. Moreover, many installations have yet to implement or have only recently implemented utility metering to the degree necessary for such a study. Electric meters have only been required since October 1, 2012, according to Section 103 of Energy Policy Act of 2005 (EPAct 2005)[9] and gas meters will be required at all installations by October 1, 2015, according to the Energy Independence and Security Act of 2007 (EISA

[9] Public Law 109-58; DOE/EE-0312, p ii.

2007).[10] Therefore, the required annual data were only available for a handful of installations and buildings at the time of this study. Additionally, although data were available for Climate Zone 4A buildings, only electric was recorded in 15-minute increments. Gas data were provided on a monthly basis and recorded hourly.

4.3 Data scrubbing

Although most data were obtained directly from MDMS, the data required significant refinement before use. Most likely because Army installations and their respective energy managers are individually responsible for all MDMS data, the downloaded energy consumption figures proved to be of poor and inconsistent quality. Without oversight from MDMS administrators or a means to standardize the information provided to MDMS, energy data are bound to vary between these installations. Therefore, to achieve the uniformity required for a thorough analysis, the downloaded MDMS data were “scrubbed” with a tool developed with Microsoft Excel Visual Basic for Applications (VBA). An example screen of this data-scrubbing tool can be seen in Figure 5, and functions are listed in Table 9. Depending on the type of data errors, various combinations of data-scrubbing routines were applied to yield data appropriate for use in benchmarking.

[10] Public Law 110-140.

Figure 5. The 'datacleanup' tab of the Excel tool.

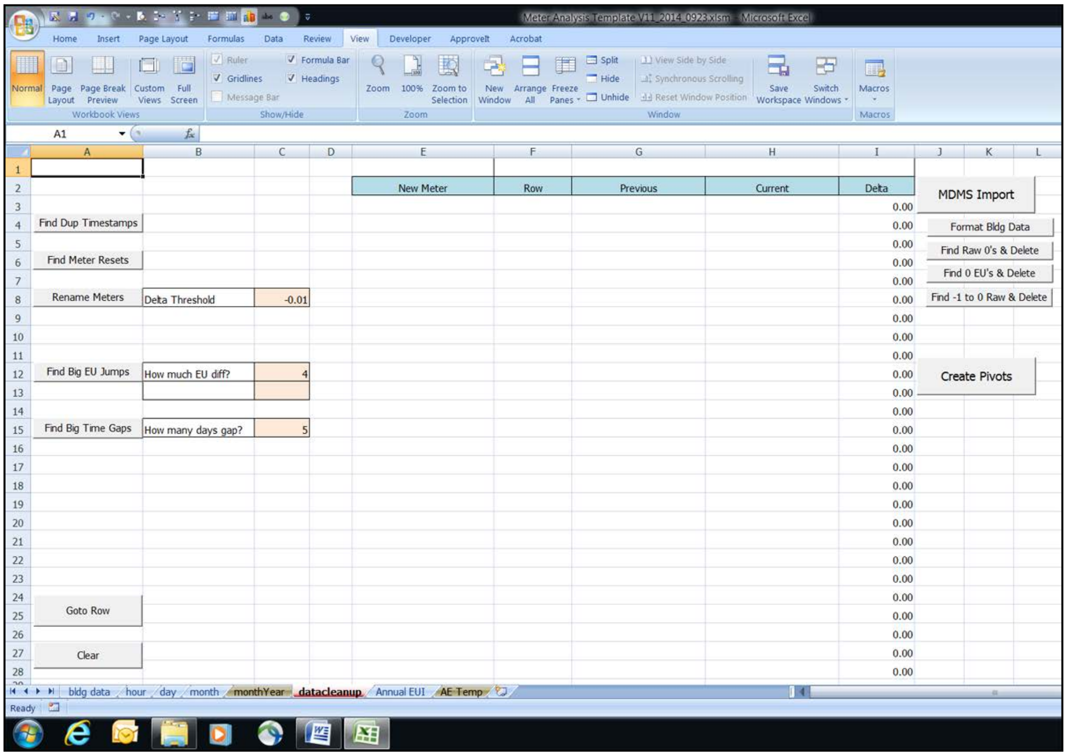


Table 9. Functions in Excel data scrubbing tool.

Button	Action	Formatting
Find Dup Timestamps	Finds data entries in 'bldg data' worksheet with same date and time (e.g. those related to Daylight Savings Time), or finds first entry of new meter.	highlights duplicate timestamps orange; highlights meter name changes red
Find Meter Resets	Finds net negative energy usage entries in 'bldg data' worksheet.	highlights negative energy usage orange; highlights meter name changes red
Rename Meters	Used to change meter names for legitimate meter resets (e.g. power outages, maximum meter digits exceeded, etc.); requires that 'Find Meter Resets' results be displayed.	appends meter name with 01, 02, etc.; highlights meter name changes red
Find Big EU Jumps	Finds specified increase in energy usage between rows in 'bldg data' worksheet.	highlights big EU jumps orange; highlights meter name changes red
Find Big Time Gaps	Finds specified time gap in 'bldg data' worksheet.	highlights big time gaps orange; highlights meter name changes red
Goto Row	Goes to row on 'bldg data' worksheet when row is selected on the 'datacleanup' results table.	n/a
Clear	Clears table data on the 'datacleanup' worksheet and clears row highlighting on the 'bldg data' worksheet.	n/a
MDMS Import	Imports and formats data from open 'MDMS data file' into 'bldg data' worksheet.	formats fonts, alignment, and borders; autosizes columns; and sorts data by meter then timestamp
Format Bldg Data	Performs MDMS Import button formatting function without importing data.	formats fonts, alignment, and borders; autosizes columns; and sorts data by meter then timestamp

Button	Action	Formatting
Find Raw 0s & Delete	Finds and deletes all rows with meter read values of zero (0).	n/a
Find 0 EUs & Delete	Finds raw usage readings that are identical for two or more consecutive rows and deletes subsequent rows (i.e. rows with no net energy consumption).	n/a
Find -1 to 0 Raw & Delete	Finds and deletes all rows with miniscule (i.e. negligible) negative meter read values.	n/a
Create Pivots	Analyzes ‘bldg data’ worksheet and populates the ‘hour’, ‘day’, ‘month’, ‘monthYear’, and ‘Annual EUI’, worksheets with the analyzed data.	n/a

4.4 Data selection

From this dataset, 115 buildings demonstrated the requisite characteristics. Upon further analysis, however, 44 of those buildings were found to contain insufficient data to establish clear benchmarks. The remaining buildings consisted of 37 barracks, 25 vehicle maintenance buildings, and 9 dining facilities (see Appendix for details).

Only the most recent, continuous, yearlong data were considered for the final 71 buildings. This implied that all buildings were not analyzed for the same time period. The analysis period is specified for each building in Table A1, Table A2, and Table A3 in the Appendix. Within those tables, both electricity and gas consumption are recorded in kBTUs and EUIs are expressed as annual kBTU/ft^2 used by the building rather than delivered by the source. Project resources did not allow for weather-normalizing of the data or normalizing for building occupancy or renovations. Also, due to the absence of sub-metering, the data do not distinguish building loads from process loads.

After finalizing the building dataset based upon the parameters explained above, the data were statistically analyzed to determine the presence of outliers. First, a Shapiro-Wilk test was performed to determine the normality of the each building type dataset. As can be seen in Table 10, both barracks and DFACs were relatively normally distributed assuming an α statistic of 0.05. Once normality was established, a Grubbs test was conducted for each building type to determine if an outlier was present within the dataset. The results of the Grubbs test are presented in Table 11 and show that no outliers within the three separate building type datasets. The potential outliers are highlighted in Table A1, Table A2, and Table A3 (see Appendix). Although vehicle maintenance buildings did not fall within a

normal distribution according to the Shapiro-Wilk test, the maximum variation from the mean for this data set was 1.72 standard deviations, which is well below the three standard deviations commonly used to consider a data point an outlier.

Table 10. Shapiro-Wilk test for normality.

	Barracks	Dining Facilities	Vehicle Maintenance
α	0.05	0.05	0.05
W	0.96	0.91	0.90
p	0.17	0.31	0.02
Normality (p>α)?	Yes	Yes	No

Table 11. Grubbs test for outliers.

	Barracks	Dining Facilities	Vehicle Maintenance
Potential Outlier	219.25 (Building B23)	577.14 Building (D4)	172.49 (Building V4)
G	2.68	1.55	1.72
G-crit	2.84	2.11	2.66
Significant	No	No	No

Having removed all erroneous data from the initial MDMS dataset, and after checking for outliers, the remaining 71 buildings were analyzed to establish the final benchmarking guidelines. Within the analysis several trends were investigated to determine which variables are most relevant for building energy performance. Although the data may not be consistent with all Army buildings, one can find interesting energy insights and determine baselines for future analysis. The following section discusses the results of the data analysis.

4.4.1 Estimating missing data—Microsoft Excel LINEST function

Upon analyzing the gas and electric meter data for barracks, dining halls, and vehicle maintenance facilities at various installations, it became apparent that several installations lacked utility data for certain months in the year. Although the cause of the missing data is unknown, such data could not be used to calculate accurate EUIs. Therefore, two attempts were made to estimate the missing values. Both techniques proved to be inadequate at capturing the data as accurately as desired.

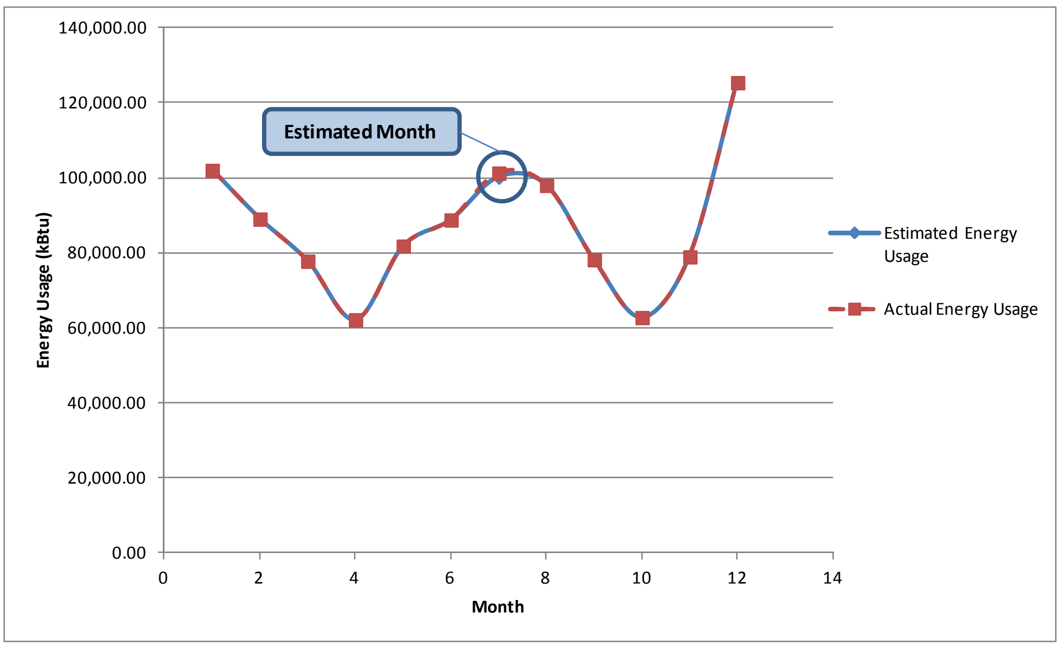
The first attempted method used the line statistics (LINEST) function built into Microsoft Excel. This function uses the least-squares method to calculate the line that best fits the available data. For this exercise, the function

was applied to calculate the equation of a 6th degree polynomial from the available meter data. The missing months were then calculated using this computed equation. Although energy usage does not follow a particular function, the 6th degree polynomial could approximate the values with the greatest accuracy. When a month was removed from a complete data set, the LINEST regression was able to calculate the missing data to within 1.1% of the actual value. The specific values can be seen in Table 12 below and the regressions can be compared in Figure 6.

Table 12. Actual vs. estimated energy usage (1 month, LINSET function, Building 1).

Electric Energy Usage (Actual)												
Month	1	2	3	4	5	6	7 (Actual)	8	9	10	11	12
Energy Usage (kBtu)	102001.31	89019.32	77795.13	62179.22	81803.78	88786.49	101277.90	98015.49	78192.00	62777.24	78956.97	125382.57
Electric Energy Usage (Estimated)												
Month	1	2	3	4	5	6	7 (Estimated)	8	9	10	11	12
Energy Usage (kBtu)	102001.31	89019.32	77795.13	62179.22	81803.78	88786.49	100167.53	98015.49	78192.00	62777.24	78956.97	125382.57
Percentage Error	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.10%	0.00%	0.00%	0.00%	0.00%	0.00%

Figure 6. Building 1 actual data also highlighting one estimated month.



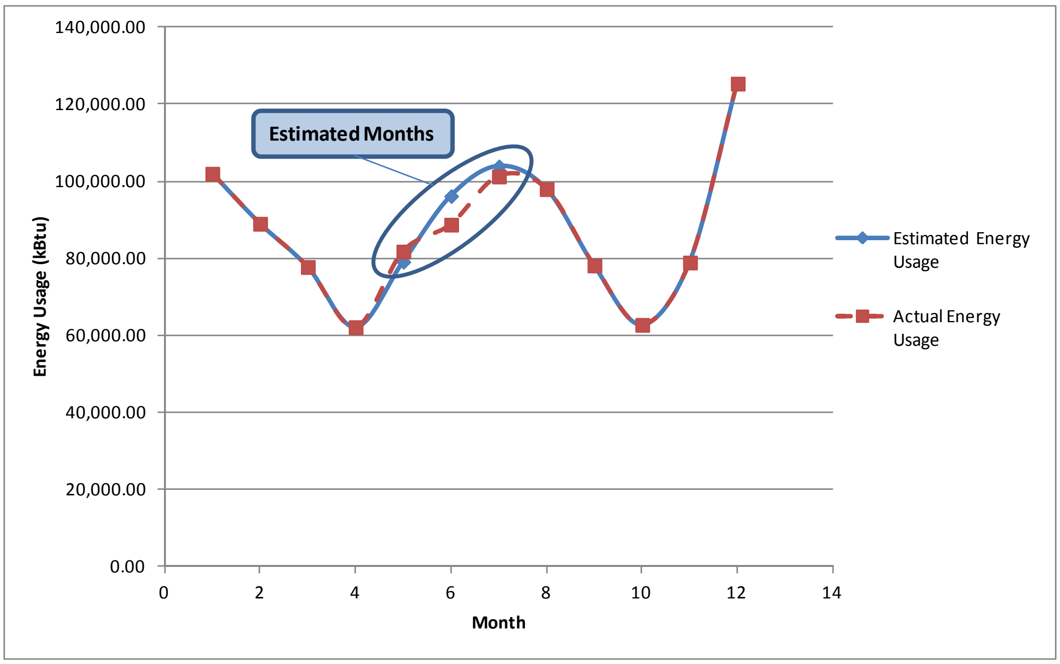
Although this method produced satisfactory results in this example, it must be noted that this regression cannot guarantee exact results. If energy usage were to increase or decrease suddenly for the missing months, the trend would not be captured by the LINEST function. Data missing at the end or the beginning of the series also cannot be estimated using this method and large gaps in the data yield inaccurate results, as can be seen in Table 13 and Figure 7. Since most buildings with limited data lacked energy consumption figures for multiple and/or consecutive months, this

method could not estimate the missing data with a reasonable amount of accuracy.

Table 13. Actual vs. estimated energy usage (3 months, LINSET function, Building 1).

Electric Energy Usage (Actual)												
Month	1	2	3	4	5 (Actual)	6 (Actual)	7 (Actual)	8	9	10	11	12
Energy Usage (kBtu)	102001.31	89019.32	77795.13	62179.22	81803.78	88786.49	101277.90	98015.49	78192.00	62777.24	78956.97	125382.57
Electric Energy Usage (Estimated)												
Month	1	2	3	4	(Estimated)	(Estimated)	(Estimated)	8	9	10	11	12
Energy Usage (kBtu)	102001.31	89019.32	77795.13	62179.22	79146.27	96192.50	103900.93	98015.49	78192.00	62777.24	78956.97	125382.57
Percentage Error	0.00%	0.00%	0.00	0.00	3.25%	-8.34%	-2.59%	0.00	0.00	0.00	0.00	0.00

Figure 7. Building 1 actual data also highlighting three estimated months.



4.4.2 Estimating missing data—proportional method

The proportional method was attempted in order to rectify the problems of encountered with the LINSET function. This method utilized a previous or subsequent year of complete data to calculate the missing values for a given building and a given year using a simple proportion relating the annual energy usage to that of the missing months, as shown in Equation 1. It was believed that the proportion could inherently factor annual climate variations and building modifications when calculating the missing data. However, as can be seen in Table 14, the percentage error between an actual set of data and estimated values is quite high. This high error was replicated for other buildings as well (Table 15).

$$\frac{a_n}{Y_1 - \sum a_i} = \frac{b_n}{Y_2 - \sum b_i} \qquad \text{Eq 1}$$

where

$$\begin{cases} Y_1 = \text{annual energy consumption for year with complete data} \\ a_n = \text{energy consumption for month in } Y_1 \text{ corresponding to } b_n \\ b_n = \text{energy consumption for missing month in } Y_2 \\ Y_2 = \text{annual energy consumption for year with missing months} \\ \sum a_i = \text{energy consumption for months in } \mathrm{Y}_1 \text{ corresponding to missing months in } Y_2 \\ \sum b_i = \text{Energy consumption for missing months in } Y_2 \end{cases}$$

Table 14. Actual vs. estimated energy usage
(3 months, proportional method, Building 1).

Electric Energy Usage 2012												
Month	1	2	3	4	5 (Actual)	6 (Actual)	7 (Actual)	8	9	10	11	12
Energy Usage (kBtu)	109571.97	89653.98	83542.88	64351.29	67280.21	68145.15	81072.08	91705.58	81445.27	74600.92	114377.15	84398.00
Electric Energy Usage 2010 (Actual)												
Month	1	2	3	4	5 (Actual)	5 (Actual)	5 (Actual)	8	9	10	11	12
Energy Usage (kBtu)	102001.31	89019.32	77795.13	62179.22	81803.78	88786.49	101277.90	98015.49	78192.00	62777.24	78956.97	125382.57
Electric Energy Usage 2010 (Estimated)												
Month	1	2	3	4	5 (Estimated)	6 (Estimated)	7 (Estimated)	8	9	10	11	12
Energy Usage (kBtu)	102001.31	89019.32	77795.13	62179.22	65641.72	66485.60	79097.72	98015.49	78192.00	62777.24	78956.97	125382.57
Percentage Error	0.00%	0.00%	0.00%	0.00%	19.76%	25.12%	21.90%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 15. Actual vs. estimated energy usage
(3 months, proportional method, Building 2).

Electric Energy Usage 2012												
Month	1	2	3	4	5 (Actual)	6 (Actual)	7 (Actual)	8	9	10	11	12
Energy Usage (kBtu)	44010.46	39092.79	12797.00	41609.16	35204.57	39067.97	35766.48	32191.00	34759.93	33259.21	34181.13	23808.71
Electric Energy Usage 2013 (Actual)												
Month	1	2	3	4	5 (Actual)	5 (Actual)	5 (Actual)	8	9	10	11	12
Energy Usage (kBtu)	28437.03	20355.47	27146.35	20493.77	22661.74	28152.49	32605.58	32349.26	28112.19	22094.06	24649.96	26341.74
Electric Energy Usage 2013 (Estimated)												
Month	1	2	3	4	5 (Estimated)	6 (Estimated)	7 (Estimated)	8	9	10	11	12
Energy Usage (kBtu)	28437.03	20355.47	27146.35	20493.77	27379.39	30384.04	27816.40	32349.26	28112.19	22094.06	24649.96	26341.74
Percentage Error	0.00%	0.00%	0.00%	0.00%	-20.82%	-7.93%	14.69%	0.00%	0.00%	0.00%	0.00%	0.00%

Given the relatively high error rate for both methods, it was determined that estimating the missing data would increase the uncertainty of the final results. Therefore, neither method was implemented. Only the buildings with at least one complete, uninterrupted year of data were considered. Although this reduced the size of the available data set, it ensured that the data were representative of the actual conditions.

4.5 Results

The final set of 71 buildings provided a means to investigate various energy consumption statistics at Army installations. The results of these investigations were then used to establish the benchmarking criteria. To understand the relationships between the various investigated parameters, the following charts were generated for each building type:

- EUI vs. Construction Year
- EUI vs. Floor Area (ft^2)
- Annual Energy Consumption vs. Floor Area (ft^2)
- EUI (Electric, Gas, and Combined) vs. Climate Zone
- Annual Energy Consumption vs. Climate Zone

Additionally, mean and median EUIs were calculated for the following criteria:

- Construction Year
- Construction Type
- Floor Area (ft^2)

The results of parameter comparisons and analyses are discussed in the sections that follow.

4.5.1 Parameter relationships: construction year and construction type

Figure 8, Figure 9, and Figure 10 compare barracks, dining facility, and vehicle maintenance building EUIs, respectively, to the year the building was constructed. From these charts, it can be seen that most buildings were constructed in the 1960s or after the 1980s. Barracks constructed after 1960 but before 1980 tend to have higher EUIs than other buildings, while DFACs have relatively uniform EUIs over all construction years. Conversely, vehicle maintenance buildings have become more energy inefficient in recent years, with the lowest EUIs seen among buildings built between the 1960s and the 1980s.

Some of these trends can be explained by the location of construction. For example, most vehicle maintenance buildings built in the 1960s were located in Climate Zone 5B, which experiences relatively temperate weather patterns. On the contrary, barracks built in the 1960s were located in Climate Zone 4A, which experiences greater weather extremes. Nevertheless, even within climate zones, there appears to be a decrease in EUI for barracks built before 1960 and after 1980, while EUIs seem to increase for vehicle maintenance buildings built in the same timeframe.

When comparing construction years to construction types (Figure 11) for these buildings, it is seen that block, brick veneer, and “other” construction techniques were the most common construction methods until recently. This may partially explain the relationship between building EUI

and the year of construction. As building methods have progressed over the years, buildings have become more energy efficient with tighter envelopes and reduced energy consumption.

More variations between construction types and construction years can been seen in Table 16 and Table 17, which compare mean and median EUIs, respectively, to these parameters for a given building type.

Figure 8. EUI vs. construction year (barracks).

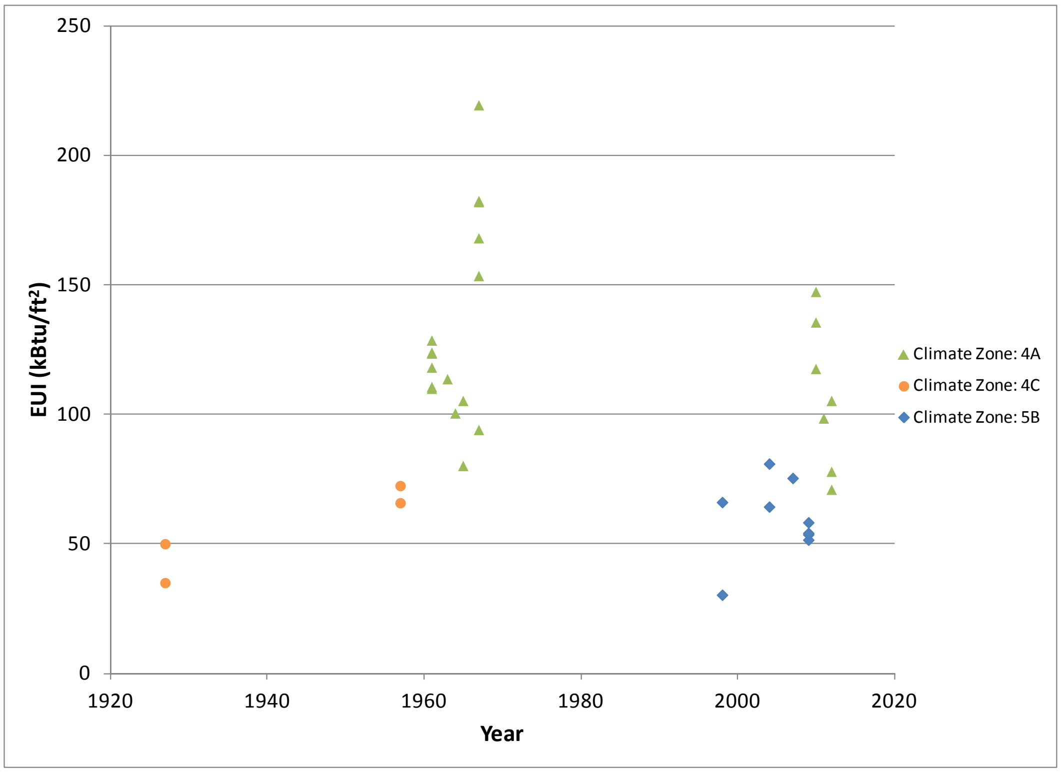


Figure 9. EUI vs. construction year (DFACs).

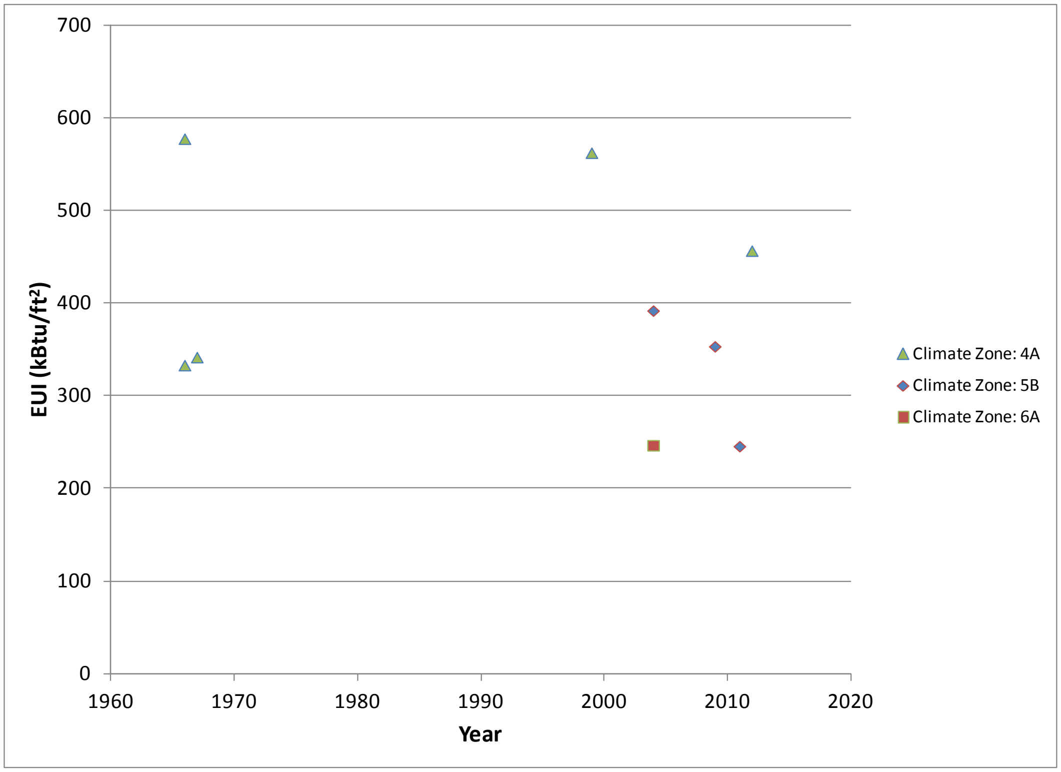


Figure 10. EUI vs. construction year (vehicle maintenance).

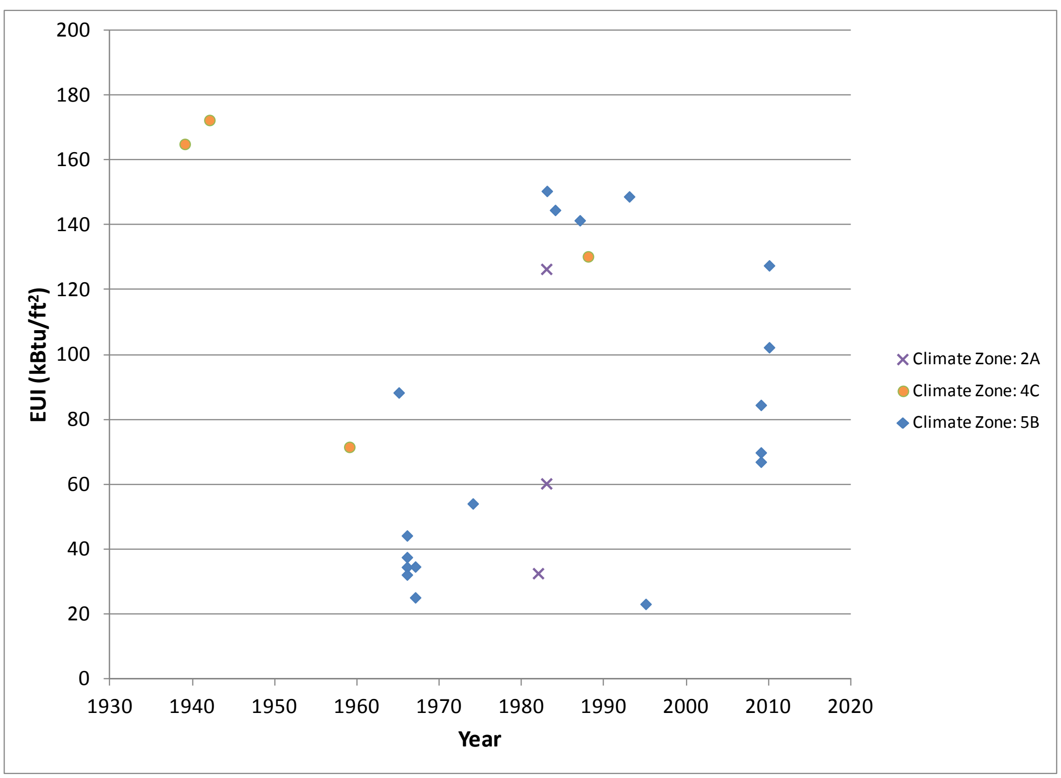


Figure 11. Construction year vs. construction type.

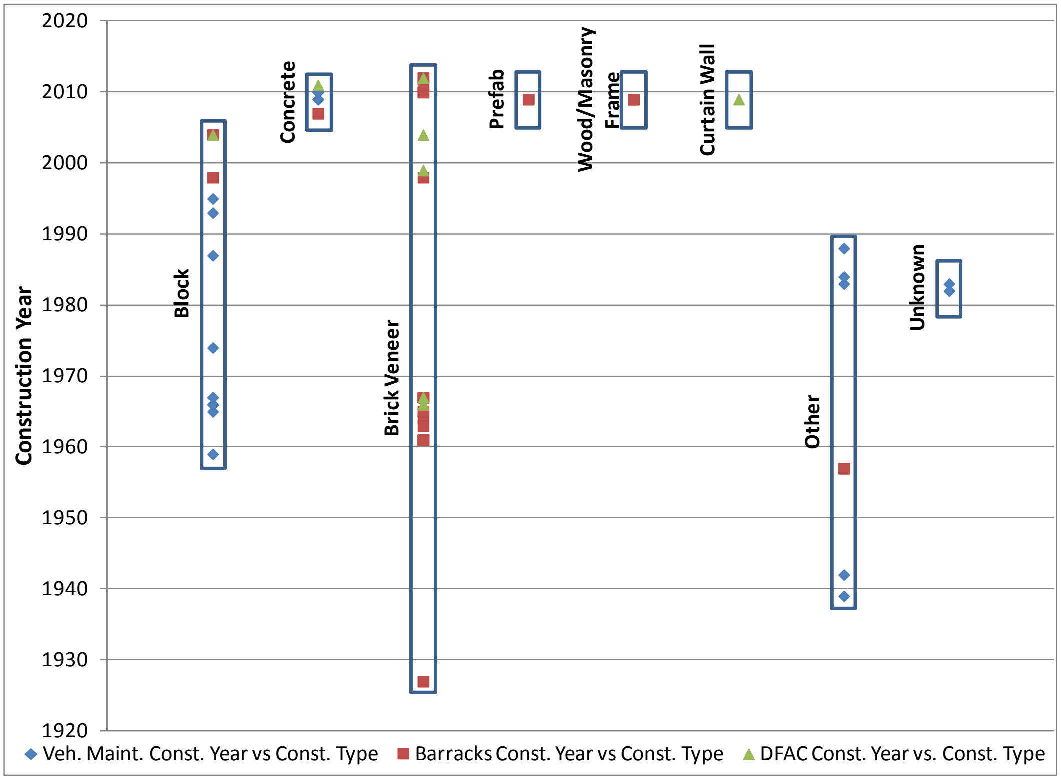


Table 16. Construction year and construction type mean EUIs.

Construction Year	Barracks	DFACs	Veh. Maint.
Before 1950	42.30	N/A	168.80
1950-1960	68.94	N/A	71.68
1960-1970	131.96	417.07	42.50
1970-1980	N/A	N/A	54.23
1980-1990	N/A	N/A	112.37
1990-2000	48.23	561.99	86.09
2000-2010	59.06	330.23	73.90
After 2010	107.44	350.75	115.04
Construction Type	**Barracks**	**DFACs**	**Veh. Maint.**
Block	58.55	391.56	61.43
Brick Veneer	115.93	419.28	N/A
Combo: Wood/Masonry Frame	53.14	N/A	N/A
Concrete	75.41	245.20	90.35
Curtain Wall	N/A	352.95	N/A
Metal	N/A	N/A	N/A
Other	68.94	N/A	152.68
Prefab	46.19	N/A	N/A

Table 17. Construction year and construction type median EUIs.

Construction Year	Barracks	DFACs	Veh. Maint.
Before 1950	42.30	N/A	168.80
1950-1960	68.94	N/A	71.68
1960-1970	120.69	341.34	34.78
1970-1980	N/A	N/A	54.23
1980-1990	N/A	N/A	130.44
1990-2000	48.23	561.99	86.09
2000-2010	56.24	352.95	69.97
After 2010	105.11	350.75	115.04
Construction Type	**Barracks**	**DFACs**	**Veh. Maint.**
Block	64.35	391.56	41.02
Brick Veneer	112.01	398.82	N/A
Combo: Wood/Masonry Frame	53.64	N/A	N/A
Concrete	75.41	245.20	84.63
Curtain Wall	N/A	352.95	N/A
Metal	N/A	N/A	N/A
Other	68.94	N/A	150.61
Prefab	46.19	N/A	N/A

4.5.2 Parameter relationships: floor area

As seen in Figure 12, Figure 14, and Figure 16, the relationships between EUI and floor area generally meet expectations as do the relationships between total energy consumption and floor area (Figure 13, Figure 15, and Figure 17). Energy consumption tends to increase with square footage, while EUIs remain relatively constant as square footage increase. Two discrepancies from these expectations must be noted, however.

Among barracks, buildings in Climate Zone 4A seem to have different EUIs for the same floor area. EUIs range from 70.85 to 218.25 kBTU/ft^2. Similarly, EUIs for vehicle maintenance buildings in Climate Zone 5b do not remain constant as floor area changes. For this building type at this location, EUI tends to increase with square footage. This implies that other factors dictate the energy consumption of these buildings more than square footage alone.

Figure 12. EUI vs. floor area (barracks).

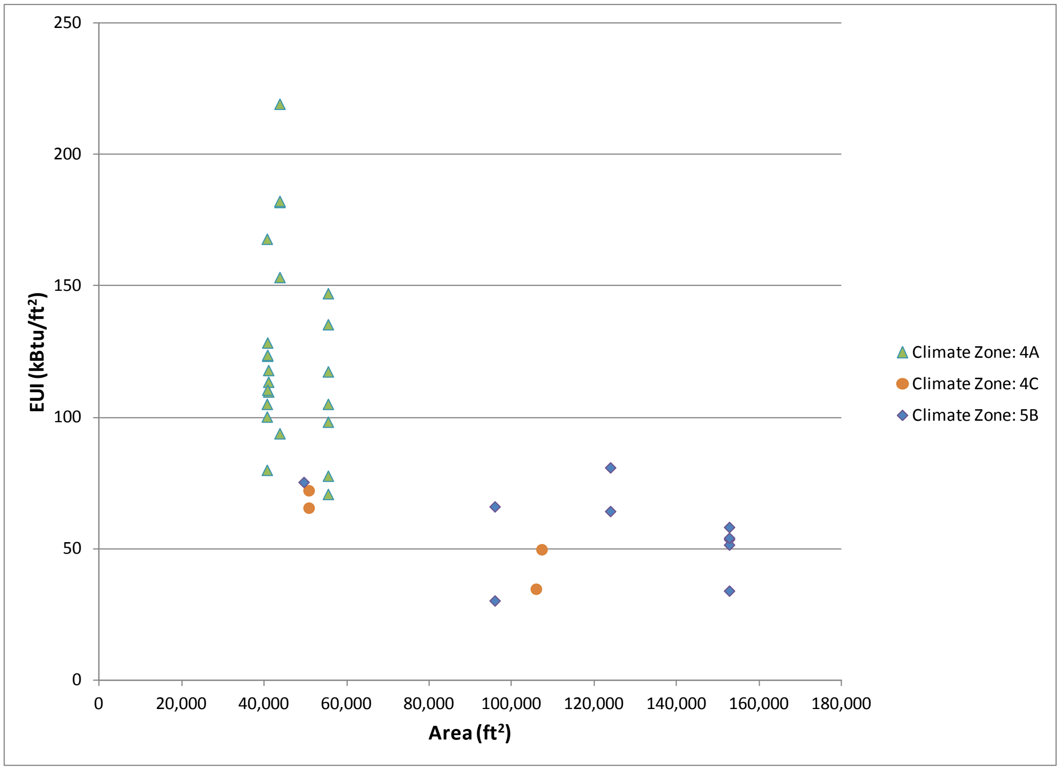


Figure 13. Annual energy consumption vs. floor area (barracks).

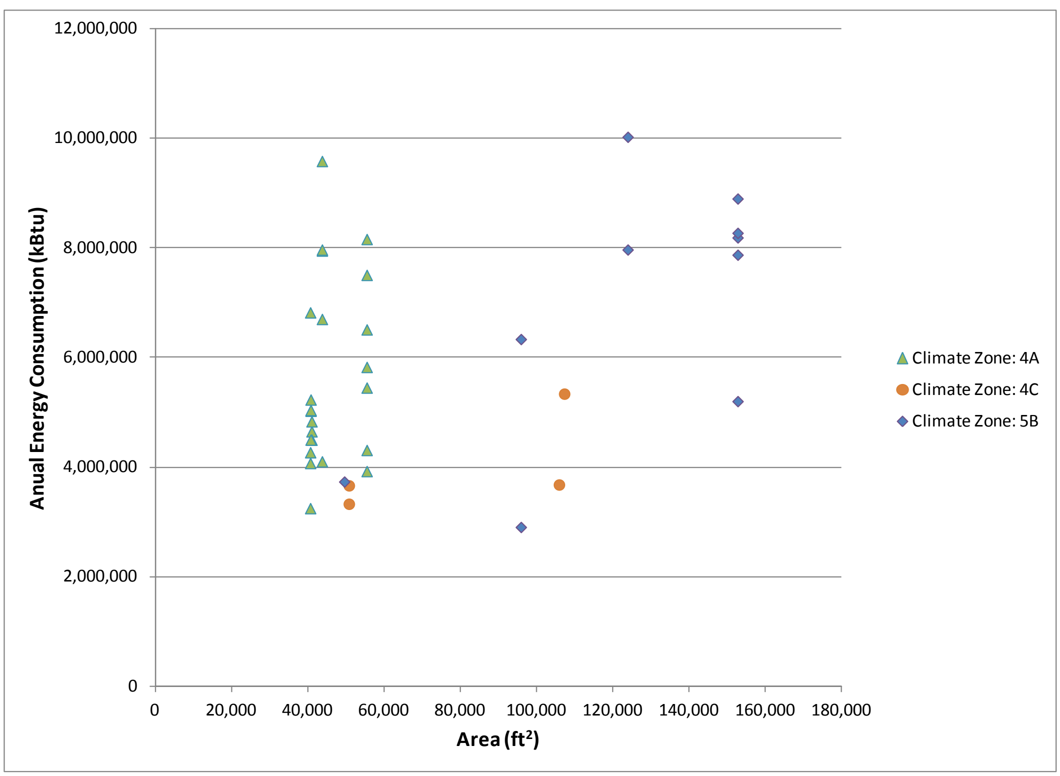


Figure 14. EUI vs. floor area (DFACs).

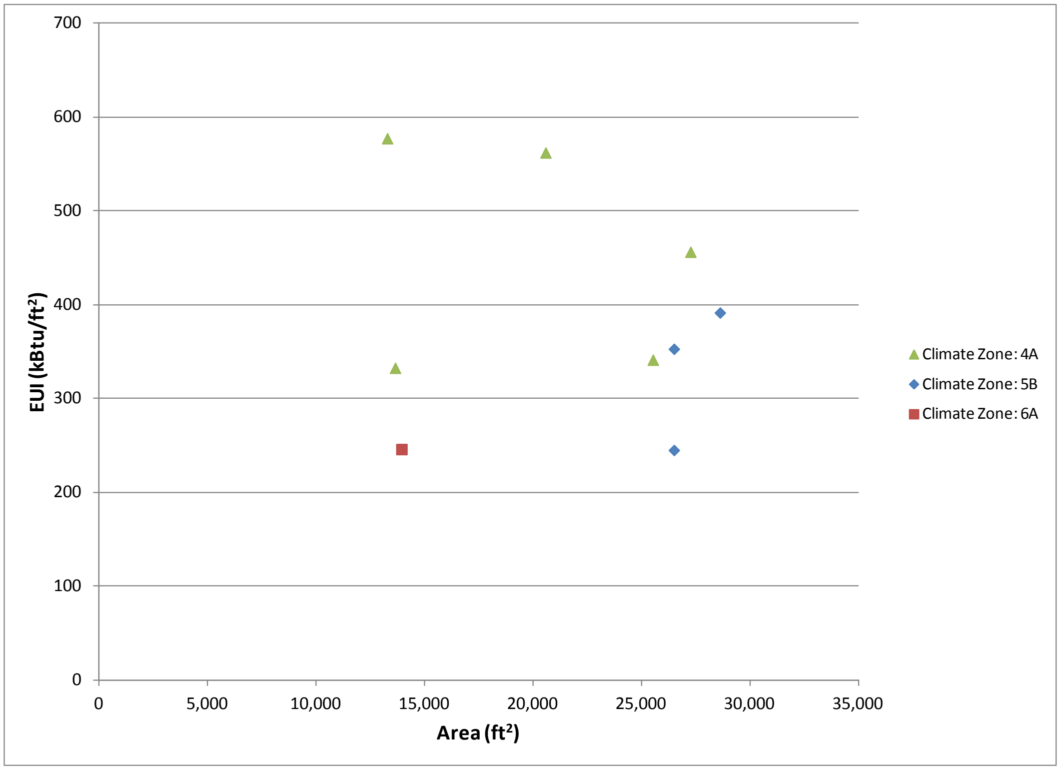


Figure 15. Annual energy consumption vs. floor area (DFACs).

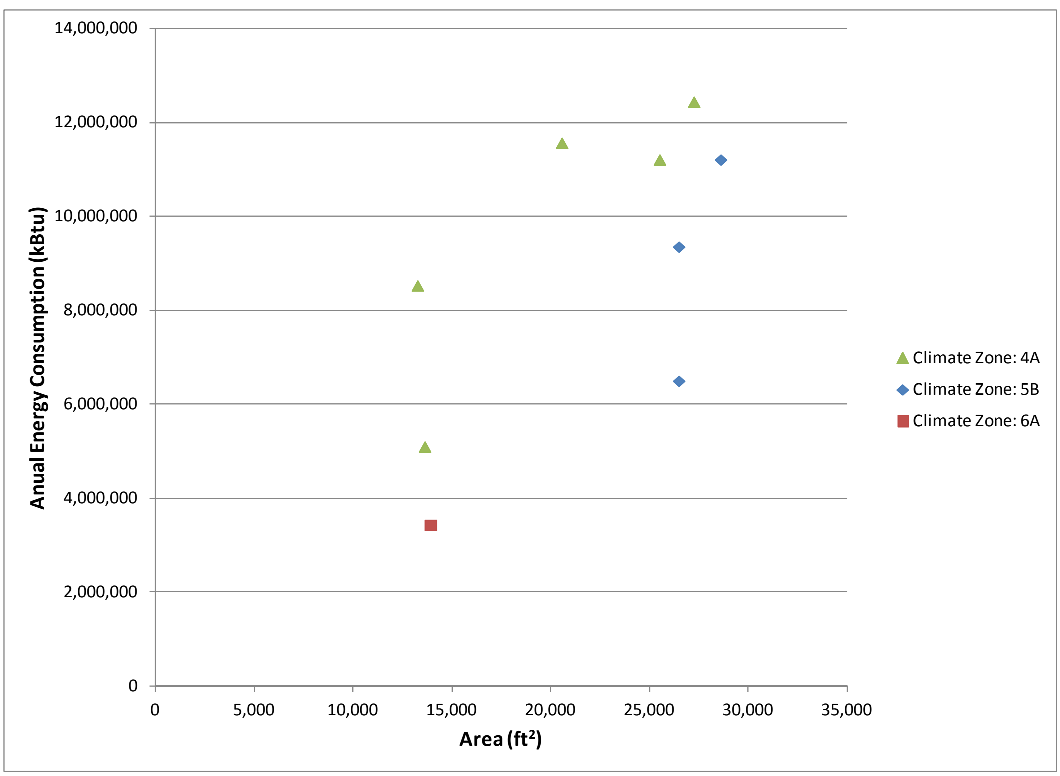


Figure 16. EUI vs. floor area (vehicle maintenance).

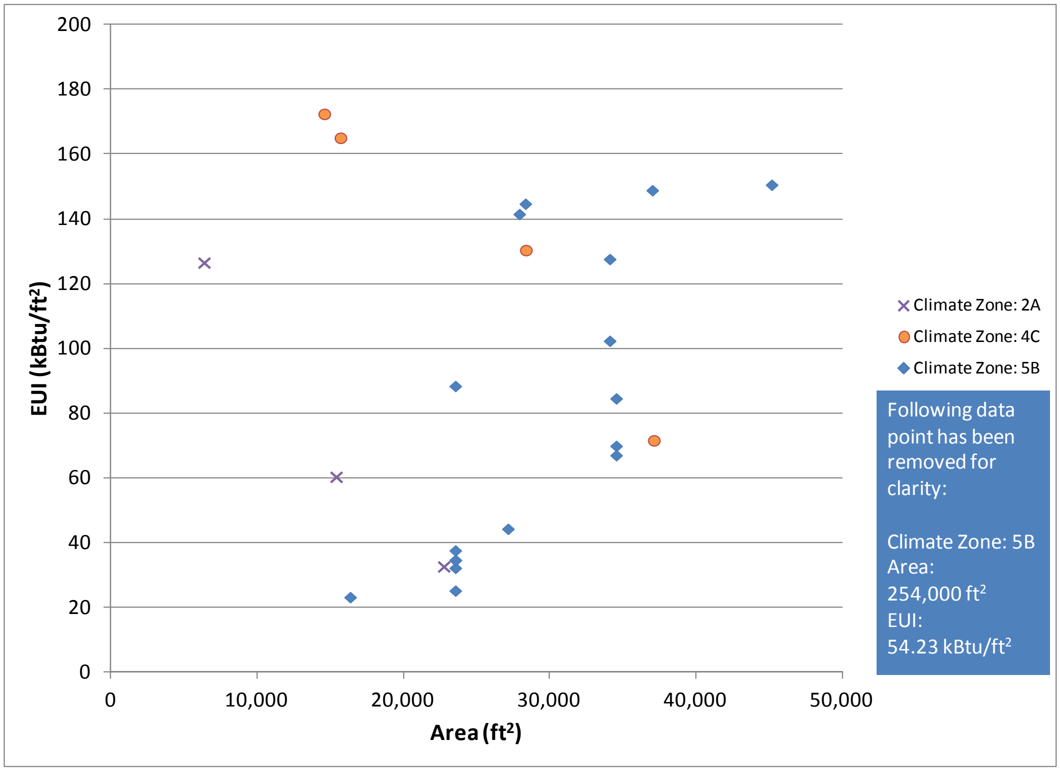
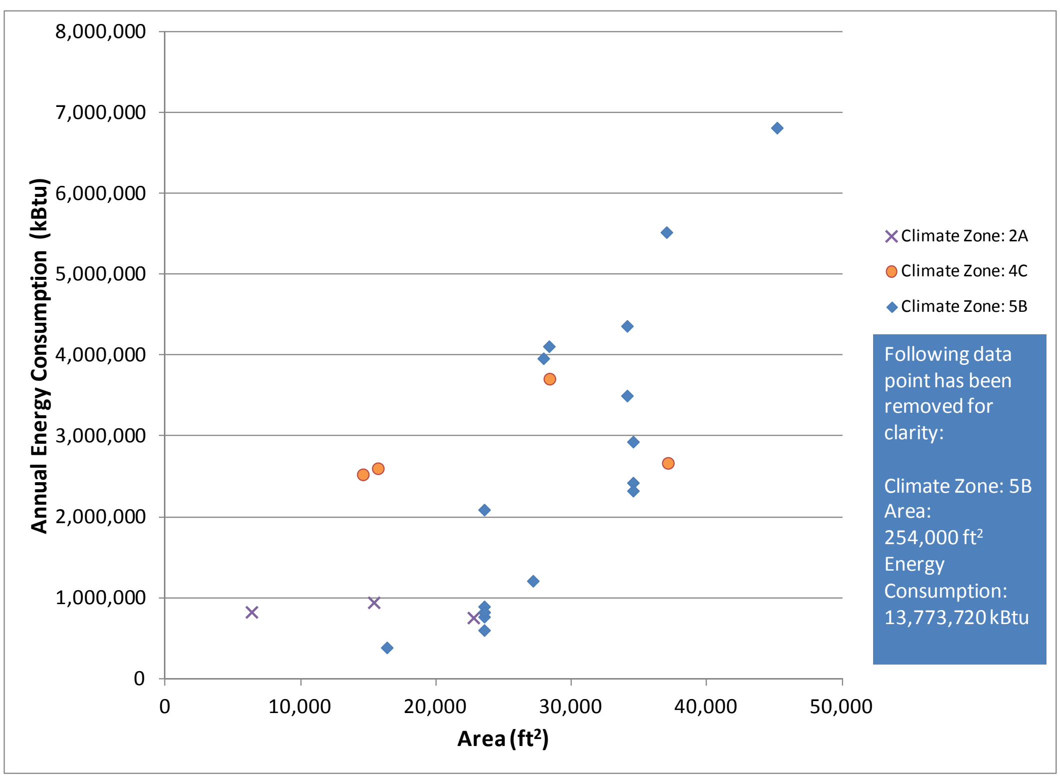


Figure 17. Annual energy consumption vs. floor area (vehicle maintenance).



4.5.3 Parameter relationships: location

As discussed in the previous sections, building location appears to influence energy usage more than the other investigated parameters. This is as expected given the temperature and weather variations between climate zones. Figure 18, Figure 21, and Figure 24 highlight the effects of these location-based differences. Figure 19, Figure 22, and Figure 25 further segment the data into gas and electric EUIs for each location and building type, while Figure 20, Figure 23, and Figure 26 plot electric and gas energy consumption at the various climate zones.

From these charts, one can see that Climate Zone 4A tends to have the highest EUIs as well as higher annual energy consumption levels. Buildings in Zone 4A appear to consume more gas and electricity than similar buildings in other climate zones given similar floor areas. As explained above, this result may be explained by the greater temperature/weather variations associated with the area.

The segmented data show that buildings tend to use more natural gas than electricity as measured in $kBtu/ft^2$. This relationship could be explained by various factors but without more data and a more detailed analysis a definite conclusion cannot be drawn. Some possibilities include the need for domestic hot water, greater heating inefficiencies, or the need to reheat chilled air for humidity control. Interestingly, this trend is less relevant for barracks in Climate Zone 5B, where electricity and gas consumption are more uniform in terms of $kBtu/ft^2$. Although a definite conclusion cannot be determined for this relationship either, the relatively temperate climate may be a factor.

Figure 18. EUI vs. location (barracks).

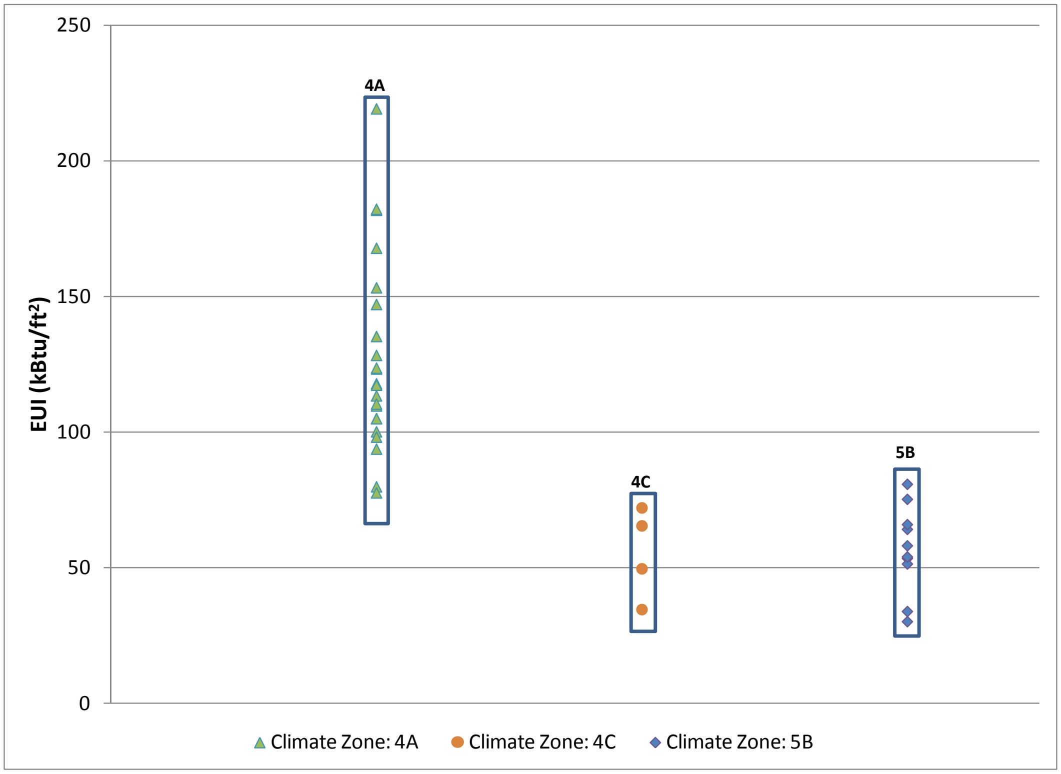


Figure 19. Electric and gas EUI vs. location (barracks).

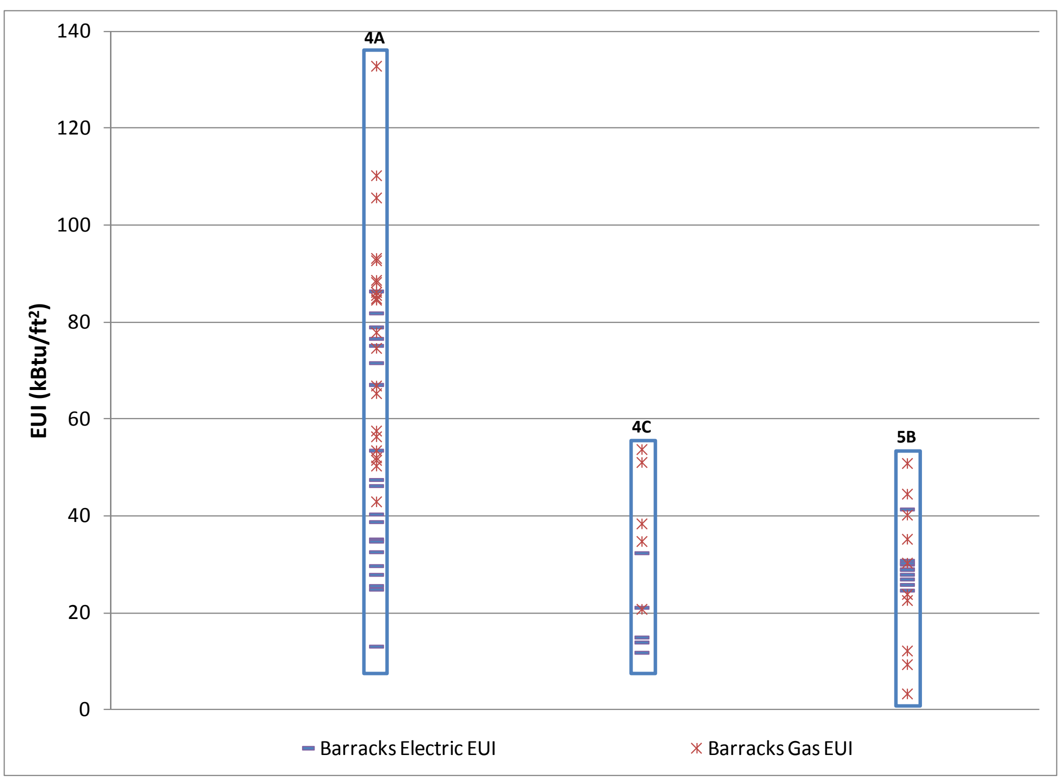


Figure 20. Electric and gas annual energy consumption vs. location (barracks).

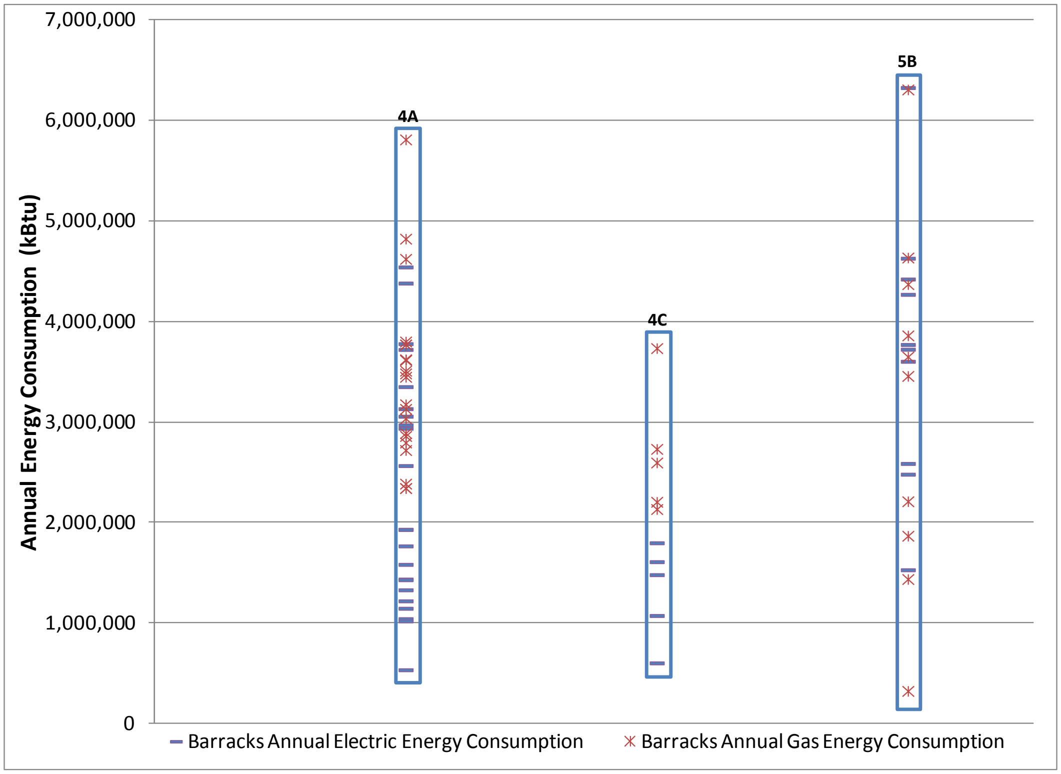


Figure 21. EUI vs. location (DFACs).

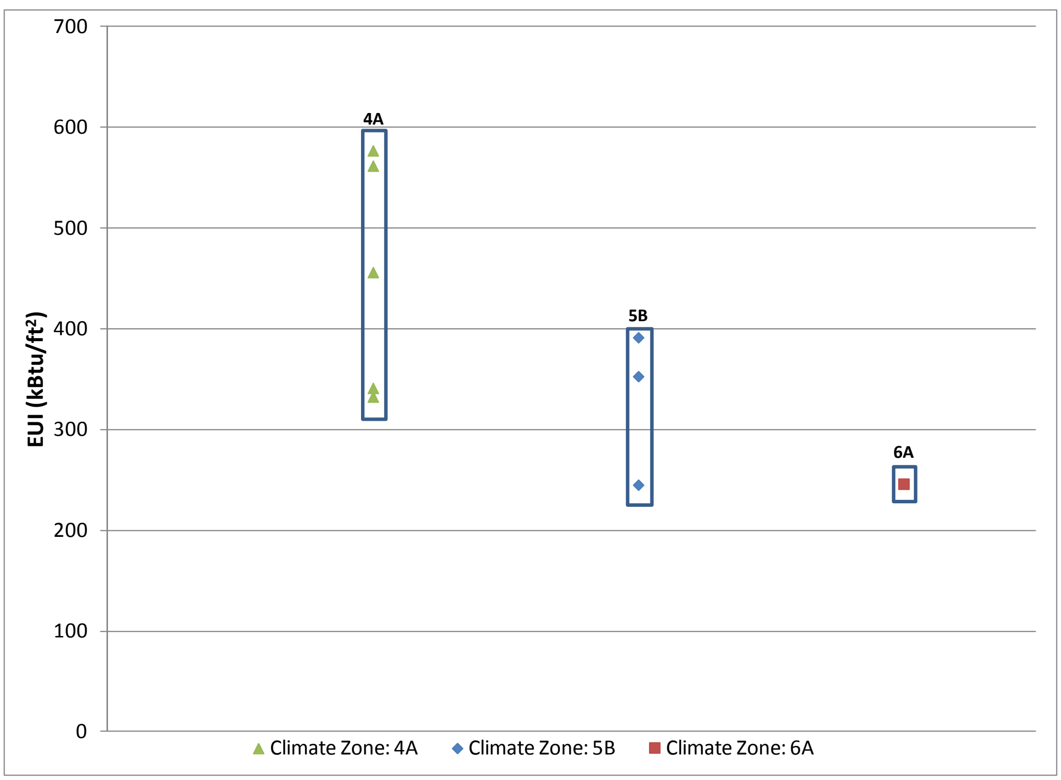


Figure 22. Electric and gas EUI vs. location (DFACs).

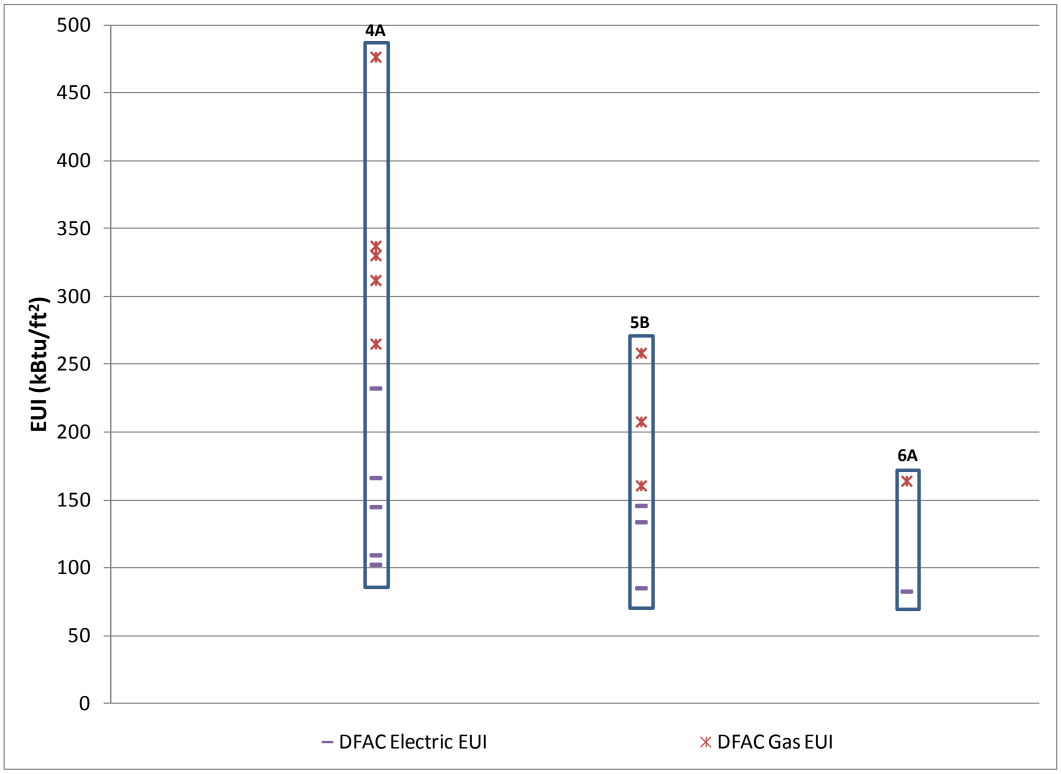


Figure 23. Electric and gas annual energy consumption vs. location (DFACs).

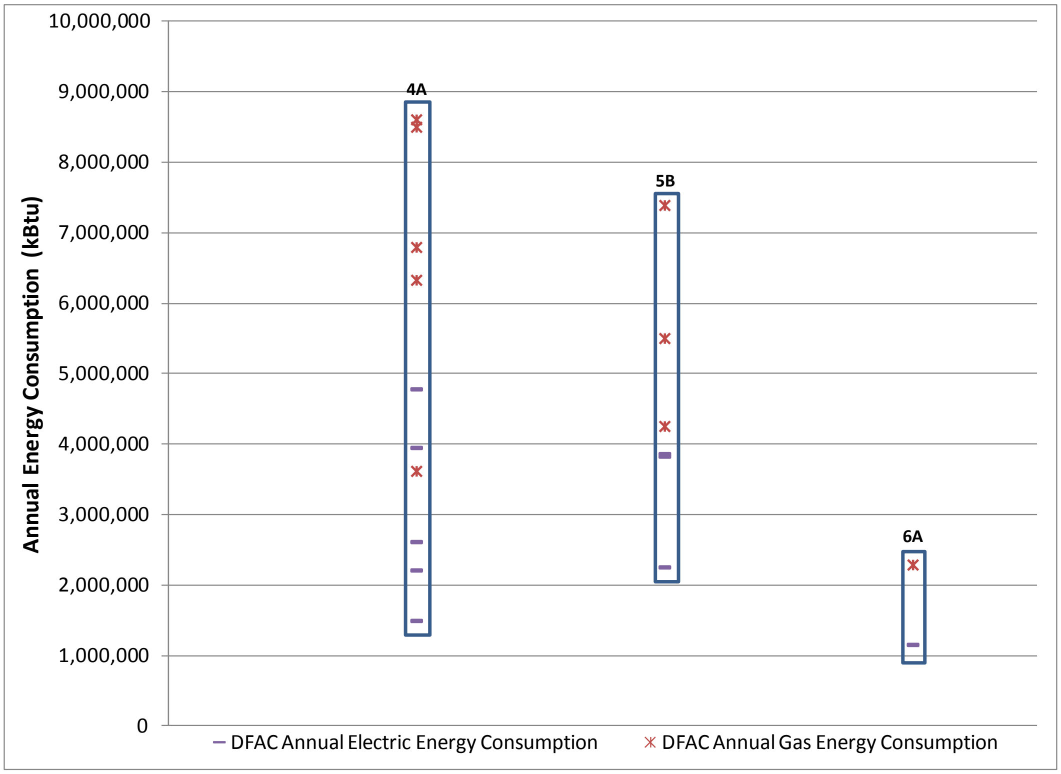


Figure 24. EUI vs. location (vehicle maintenance).

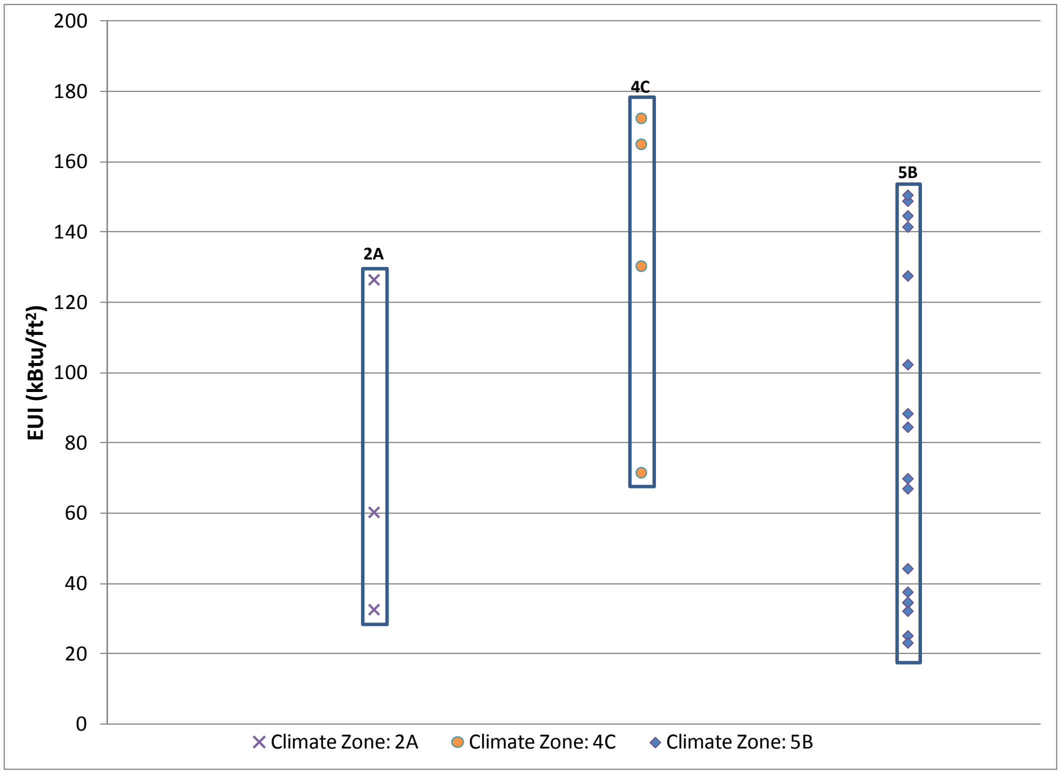


Figure 25. Electric and gas EUI vs. location (vehicle maintenance).

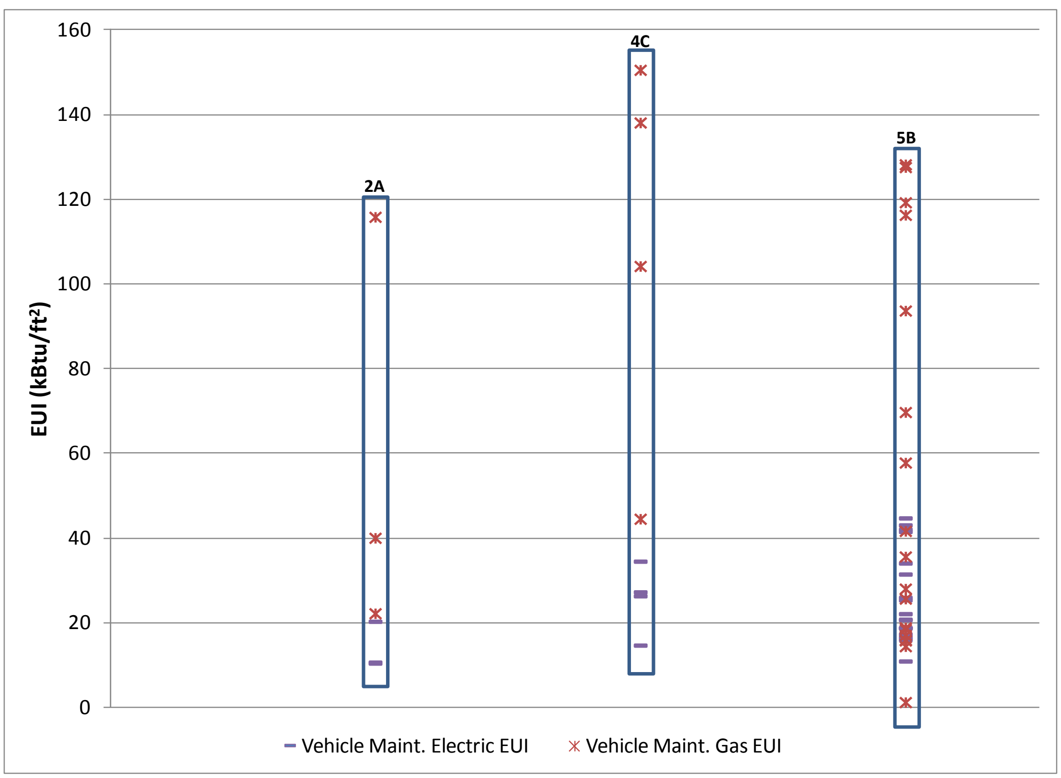
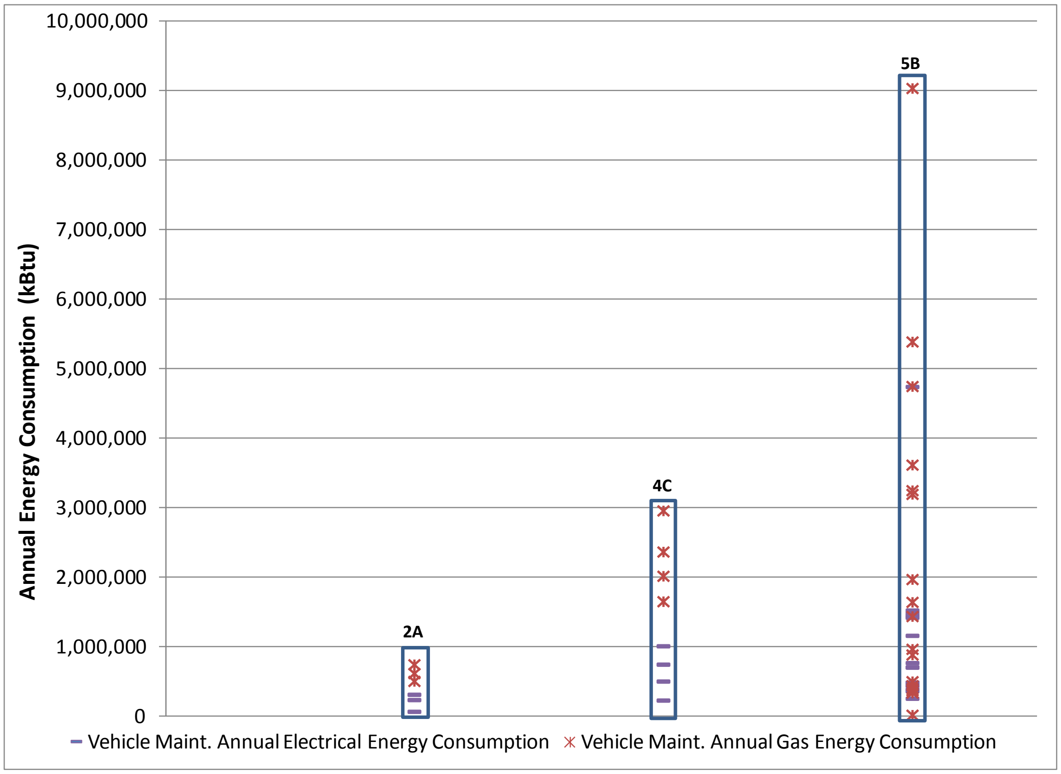


Figure 26. Electric and gas annual energy consumption vs. location (vehicle maintenance).



4.5.4 Parameter relationships between occupancy and usage

Although this study did not explicitly address the occupancy of each analyzed building, building usage appears to be a primary factor in determining overall energy consumption. In the relationships explored previously, inter-criteria discrepancies can be explained by various means, but intra-criteria variations are best explained by differences in building usage and occupancy.

For the data presented in section 4.5.3, one observes a relatively large spread of EUIs for buildings in the same climate zone and of the same building type. Table 18, Table 19, and Table 20 quantify this spread in the data by comparing the median, mean, range, and standard deviation for each climate zone and building type. These tables and the figures above show the relatively large variation in EUIs for buildings in Zone 4A. Both barracks and DFACs in Zone 4A have larger ranges and standard deviations than similar buildings at other locations. Additionally, it is seen in A1 and Table A2 of the Appendix that Zone 4A buildings have similar construction types and years, so those criteria cannot account for the variations in energy consumption. Variations in building occupancy and usage

may explain these results, but further study would be required to determine the exact relationship.

Table 18. Data spread/variation (barracks).

EUIs (kBtu/ft^2)	All	Climate Zone: 4A	Climate Zone: 4C	Climate Zone: 5B
Median	98.32	117.45	57.72	56.24
Mean	98.78	124.50	55.62	56.90
Range	188.90	148.40	37.45	50.61
Standard Deviation	45.03	36.68	16.78	16.11

Table 19. Data spread/variation (DFACs).

EUIs (kBtu/ft^2)	All	Climate Zone: 4A	Climate Zone: 5B	Climate Zone: 6A
Median	352.95	456.30	352.95	246.19
Mean	389.49	453.90	329.90	246.19
Range	331.94	244.42	146.35	0.00
Standard Deviation	121.28	116.44	75.85	N/A

Table 20. Data spread/variation (vehicle maintenance).

EUIs (kBtu/ft^2)	All	Climate Zone: 4A	Climate Zone: 5B	Climate Zone: 6A
Median	71.68	60.24	68.53	147.78
Mean	86.86	73.06	78.48	134.93
Range	149.24	93.84	127.36	100.81
Standard Deviation	49.67	48.22	46.73	45.98

4.6 Establishing benchmarks

The data discussed above were used to establish building energy benchmarks for the three building types and for each climate zone. These benchmarks separated buildings into three groups based upon their EUI and relationship to their peers. “Good” or “Green” buildings were those with EUIs in the first quartile of all buildings with the same criteria; “Bad” or “Red” buildings were those above the third quartile; and “Acceptable” or “Amber” buildings were those between the first and third quartile. Figure 27, Figure 28, and Figure 29 show the three benchmarking categories for barracks, DFACs, and vehicle maintenance buildings, respectively. Table 21, Table 22, and Table 23 provide the exact quartile values for each climate zone and building type. Within the quartile charts, the bottom whisker highlights 25% of the buildings with the lowest EUIs; the top whisker represents 25% of the buildings with the worst EUIs; and the middle amber box contains the remaining 50% of buildings. The dark line within the box is representative of the median of the dataset.

The quartile charts show that the variability of the data differs considerably between building types and locations. Depending on location, the three benchmarking classifications may have smaller or larger EUI ranges. Therefore, a small change in a building's EUI could cause a shift in its performance rating or a large shift could have a negligible impact.

Quartiles were selected as the benchmarking criteria because they provide a quantitative means for gauging where a target building stands in comparison to similar buildings. Quartiles can also be dynamically changed as building energy performance improves. This enables users to rapidly shift the Good, Bad, and Acceptable standards as necessary to accommodate changes in consensus baselines or revisions of government or industry standards.

Additionally, quartile ratings can be easily automated and integrated into additional energy-modeling software. In this study, the benchmarks were used to inform the BUILDER™ Sustainment Management System[11] Energy module as to whether an energy-efficiency measure (EEM) or set of EEMs would allow buildings under analysis to meet or exceed peer norms. Such analyses can help building managers with determining how best to improve their building's energy performance.

[11] The BULDER™ Sustainment Management System (SMS) is a web-based software application developed by ERDC-CERL to support the DoD facilities management community optimize infrastructure maintenance planning, scheduling, and resource allocation. More information about BUILDER™ is available at http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/476728/builder-sustainment-management-system/

Figure 27. Barracks benchmark quartiles.

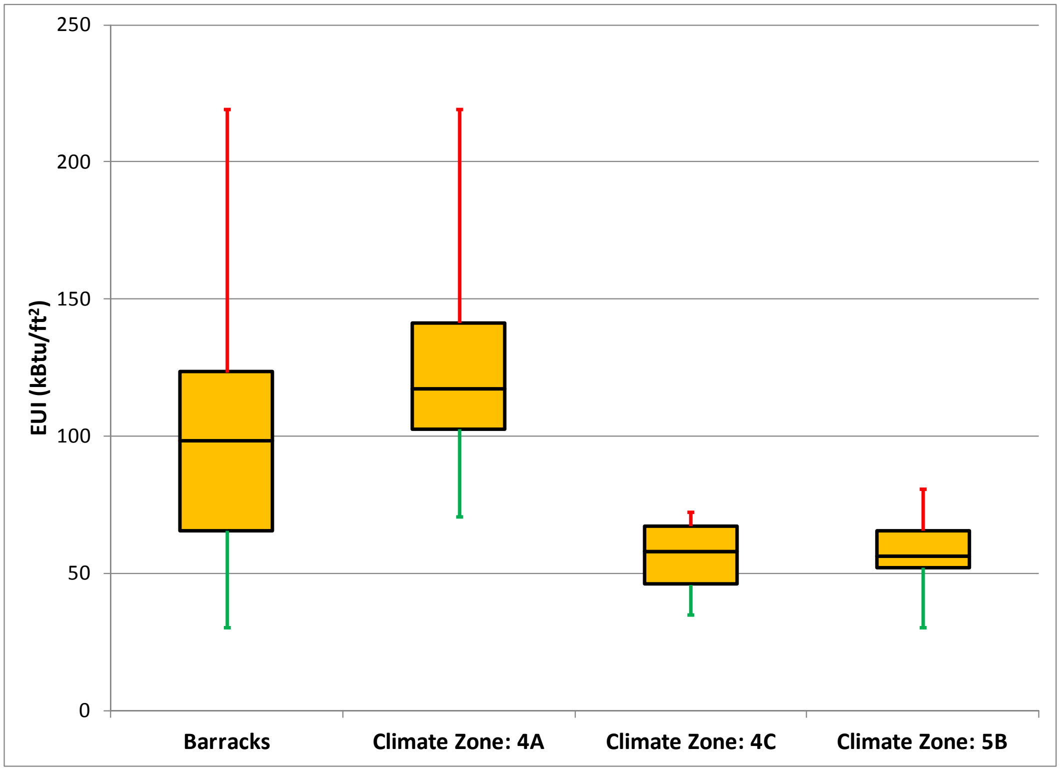


Table 21. Barracks quartile values.

EUIs (kBtu/ft^2)	Barracks	Climate Zone: 4A	Climate Zone: 4C	Climate Zone: 5B
Minimum	30.34	70.85	34.80	30.34
1st Quartile	65.64	102.69	46.06	52.10
Median	98.32	117.45	57.72	56.24
3rd Quartile	123.41	141.29	67.29	65.67
Maximum	219.25	219.25	72.25	80.95

Figure 28. DFAC benchmark quartiles.

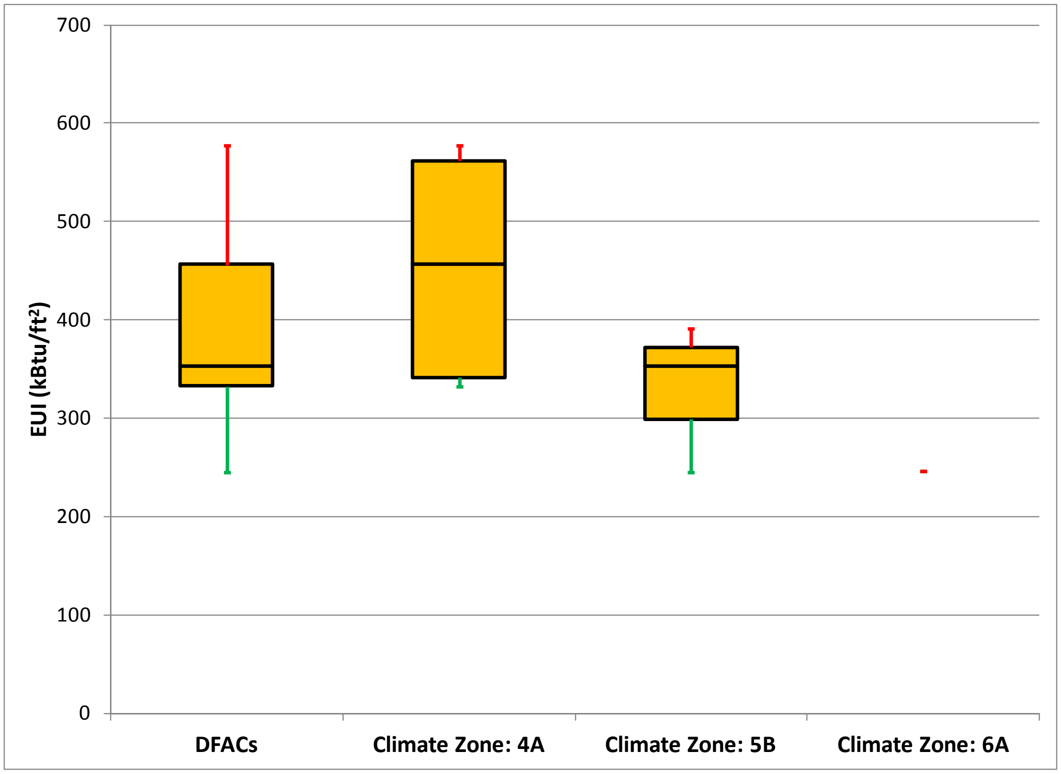


Table 22. DFAC quartile values.

EUIs (kBtu/ft^2)	DFACs	Climate Zone: 4A	Climate Zone: 5B	Climate Zone: 6A
Minimum	245.20	332.72	245.20	N/A
1st Quartile	332.72	341.34	299.07	N/A
Median	352.95	456.30	352.95	N/A
3rd Quartile	456.30	561.99	372.25	N/A
Maximum	577.14	577.14	391.56	N/A

Figure 29. Vehicle maintenance benchmark quartiles.

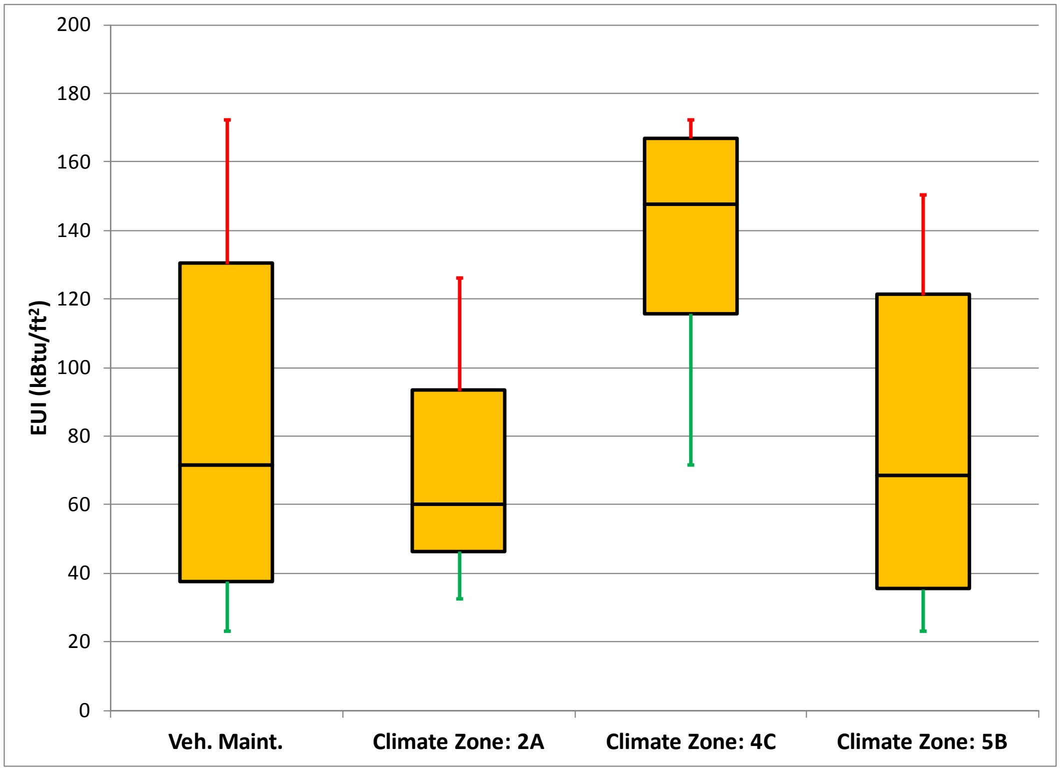


Table 23. Vehicle maintenance quartile values.

EUIs (kBtu/ft^2)	Veh. Maint.	Climate Zone: 2A	Climate Zone: 4C	Climate Zone: 5B
Minimum	23.25	32.55	71.68	23.25
1st Quartile	37.68	46.40	115.75	35.51
Median	71.68	60.24	147.78	68.53
3rd Quartile	130.44	93.32	166.96	121.35
Maximum	172.49	126.40	172.49	150.61

4.7 Comparison of Army data and commercial studies

The data presented above can be compared with the results of commercial studies at other locations. Table 24 compares the median EUIs of six additional studies with those calculated here. The commercial building types used to calculate medians in each study are provided in Table 25. An overview of each study is provided below.

Table 24. Commercial studies building EUIs.

Annual Median EUIs (kBtu/ft^2)	Barracks	Dining Facilities	Vehicle Maintenance
CBECS - 2003	73.90	228.50	49.30
CTS	65.50	146.10	189.60
DC - 2013	50.40	--	--
NYC - 2013	84.20	213.50	84.20
CEUS	83.78	347.15	--
CEC	154.00	712.00	--
Army	98.32	352.95	71.68
Mean	85.30	329.45	98.70
Standard Deviation	35.95	225.78	62.30
Army Standard Deviation from Mean	0.30	0.10	0.43

Table 25. Commercial study building datasets.

Commercial Studies	Barracks	Dining Facilities	Vehicle Maintenance
CBECS - 2003	•Dormitory •Fraternity •Sorority	•Restaurant •Cafeteria	•Vehicle service/repair shop
CTS	•Residence Hall/Dormitory	•Food service •Restaurant/cafeteria	•Vehicle service/repair •Vehicle
DC - 2013	•Residence Hall/Dormitory	N/A	N/A
NYC - 2013	•Residence Hall/Dormitory	•Restaurant •Food service	•Automobile dealership
CEUS	•Lodging	•Restaurant	N/A
CEC	•Lodging, Motel	•"Other" restaurant	N/A

4.7.1 Commercial Buildings Energy Consumption Survey (CBECS)[12]

The Commercial Buildings Energy Consumption Survey (CBECS) is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures). Commercial buildings in this definition includes all buildings in which at least half of the floor space is used for a purpose that is not residential, industrial, or agricultural. This includes schools, hospitals, and correctional institutions, in addition to "traditional" commercial building uses.

[12] *U.S. Energy Information Administration - EIA - Independent Statistics and Analysis*. (n.d.). Retrieved November 13, 2015, from http://www.eia.gov/consumption/commercial/

CBECS is administered by the U.S. Department of Energy's (DOE) Energy Information Administration (EIA). The EIA was created in 1978, along with the DOE, after the 1973 oil embargo revealed a need to cut the nation's dependence on foreign oil. Its primary mission is to gather data on U.S. energy supply and demand. The EIA conducted its first CBECS in 1979, followed by surveys in 1983, 1986, 1989, 1992, 1995, 1999, and 2003. The upcoming 2012 CBECS, due to roll out in 2016, will be the ninth iteration.[13]

4.7.2 EISA 432 Compliance Tracking System (CTS)

The CTS is the repository for all federal benchmarking efforts (including MDMS output). It is overseen by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. The CTS consists of five data sets that can be used to build custom reports (1) facility annual detail, (2) comprehensive evaluation detail, (3) benchmarked building detail, (4) project and follow-up detail and, the most recent, (5) facility overview.[14][15]

4.7.3 Washington, DC

Data disclosures are divided into public and private buildings. Public results are published through the District Department of the Environment (DDOE) and the Department of General Services (DGS) and include 15-minute interval data for electricity use. The private building results are published by the District of Columbia annually, and include energy and water performance benchmarking data from the city's largest buildings.[16]

4.7.4 New York City, NY

Data disclosures are divided into public and private buildings. Both public and private energy benchmarking uses Portfolio Manager, which is cited as being "widely accepted as the industry standard for benchmarking."

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[13] Maria Gallucci, InsideClimate News, *National Building Audit to Reset Crucial Energy Use Benchmarks*, 7 March 2012, http://insideclimatenews.org/news/20120307/national-building-audit-reset-crucial-energy-use-benchmarks.

[14] 42 U.S.C.A. § 8253 (West).

[15] EISA Federal Facility Management and Benchmarking Reporting Requirements. (n.d.). Retrieved November 13, 2015, from http://energy.gov/eere/femp/eisa-federal-facility-management-and-benchmarking-reporting-requirements.

[16] Energy Benchmarking Disclosure. (n.d.). Retrieved November 13, 2015, from http://doee.dc.gov/page/energy-benchmarking-disclosure.

Public buildings are monitored by the Department of Citywide Administrative Services (DCAS) and include total electricity, natural gas, district steam, and heating fuel oil. Approximately 4,000 public buildings have been benchmarked since 2009. Owners of large, private buildings are mandated by Local Law 84 to annually measure their energy and water consumption.[17]

4.7.5 California Commercial End-Use Survey (CEUS)

CEUS is a study of commercial sector energy use, primarily collected to provide data for energy demand forecasting. CEUS consists of a "stratified random sample" of 2,790 commercial facilities. It is overseen by the California Energy Commission (CEC). Utility service area, floor stocks, fuel shares, electric/natural gas consumption, EUIs, energy intensities, and 16-day hourly end-use load profiles were estimated for twelve common commercial building types.[18]

4.7.6 Nonresidential Building Energy Use Disclosure Program (CEC)

The Nonresidential Building Energy Use Disclosure Program encourages greater energy efficiency in nonresidential buildings by requiring building owners to disclose energy use to prospective buyers, lessees, and lenders, as well as to the California Energy Commission. This statewide program applies in addition to benchmarking and disclosure programs already in place and under development in local jurisdictions.[19]

4.7.7 Summary of comparisons

These studies demonstrate that the Army energy usage is comparable to that reported in some commercial studies but quite different from others. Therefore, it cannot be stated conclusively that commercial studies are applicable to Army installations without further analysis. The difference between Army and commercial building occupancy and usage characteristics

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[17] Benchmarking Data Disclosure & Reports. (n.d.). Retrieved November 13, 2015, from http://www.nyc.gov/html/gbee/html/plan/ll84_scores.shtml.

[18] Itron Inc. March 2006. *California Commercial End-Use Survey.* California Energy Commission. Retrieved November 13, 2015, from http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF.

[19] Nonresidential Building Energy Use Disclosure Program (AB 1103). (n.d.). Retrieved November 13, 2015, from http://www.energy.ca.gov/ab1103/.

likely account for some of these discrepancies. While commercial buildings tend to have well regimented occupancy patterns and limited variability, Army building occupancy can change drastically as a result of deployment and training schedules. Such activities often leave Army buildings underutilized.

Additionally, it proved difficult to find commercial counterparts for Army buildings. As shown in Table 25, there are no exact matches between Army and commercial buildings. Although a dormitory, motel, or other commercial lodging facilities may have similarities with barracks buildings, the usage and occupancy patterns are not identical. Similarly, an automobile dealership differs considerably from an Army vehicle maintenance facility. Unfortunately, the building types listed in Table 25 are the closest approximations for the Army buildings studied here. Therefore, it is not surprising that Army EUIs differ from those of commercial buildings addressed in other commercial studies. Further study would be required to determine the exact occupancy, usage, and construction differences between Army and commercial buildings and how they can be accounted for when comparing the two different standards.

5 Conclusions and Recommendations

5.1 Conclusions

While Army energy data remain scarce and commercial studies are inconclusive, the analysis presented in Chapter 4 provides usable benchmarks for BUILDER and energy managers. Additional data and further studies could be used to refine the present results, but currently available data highlight where Army energy usage differs from similar commercial buildings and which buildings consume a disproportionate amount of energy. As more buildings are metered and additional energy-consumption factors are studied, the sensitivity and clarity of these benchmarks will improve.

5.2 Recommendations

5.2.1 Improve data in Army real property databases

5.2.1.1 Populate existing building attributes in HQIIS and GFEBS

Accurate populating and updating of HQIIS and GFEBS data fields would greatly facilitate benchmarking efforts currently under way by the Army. Useful data fields that are often not populated are shown in Table 26. Understanding the physical makeup of a building is fundamental to rigorous benchmarking.

Table 26. Existing building attributes in HQIIS that are often not populated with data.

Structure construction material code	FCLTY_STRUCT_CONST_MATL_CD
Foundation construction material code	FCLTY_FNDTN_CONST_MATL_CD
Floor construction material code	FCLTY_FLOOR_CONST_MATL_CD
Wall construction material code	FCLTY_WALL_CONST_MATL_CD
Roof construction material code	FCLTY_ROOF_CONST_MATL_CD

5.2.1.2 Add new building attributes to HQIIS and GFEBS

In an effort to hone Army benchmarks, it is recommended that more building attributes be added to existing Army and DoD real property databases. Recommendations are summarized in Table 27. The legacy Integrated Facilities System (IFS) database incorporated data fields that would benefit energy benchmarking activities, namely those that described physical attributes of the facilities such as those shown in Table 28.

Table 27. Building attributes for Army to consider tracking in the future (EIA).

Facility shape	Vacancy status (building hours, occupancy)	Conveyance (elevators, escalators, moving walks)
Roof type / pitch	Renovations before 1980	Window-to-wall ratio (all sides)
Attic (y/n)	Water heating	Refrigeration equipment
Cool roof	Cooking equipment	Manufacturing equipment
Lighting schedules	Office equipment	Equipment usage schedules[20]

Table 28. Useful attributes tracked in the IFS database.

CONSTRUCTION CHARACTERISTICS	
Area Total Roof	AREA_TOTAL_ROOF
Ceiling Height Basement	CEILING_HGHT_BASEMENT
Ceiling Height Feet	CEILING_HEIGHT_FEET
Facility Construction Remarks	FAC_CONSTR_RMKS
Facility Dimensions Attic	FACILITY_DIMENSIONS_ATTIC
Facility Dimensions Basement	FACILITY_DIMENSIONS_BASEMENT
Facility Dimensions Offset	FACILITY_DIMENSIONS_OFFSET
Facility Dimensions Wings	FACILITY_DIMENSIONS_WINGS
ELECTRIC	
Electric Amperes	ELECTRIC_AMPERES
Electric Kilovolt Amperes Rating	ELECTRIC_KVA_RATING
Electric Phase	ELECTRIC_PHASE
Electric Voltage	ELECTRIC_VOLTAGE
Electric Wire Size	ELECTRIC_WIRE_SIZE
GAS	
Gas Pipe Pressure	GAS_PIPE_PRESSURE
Gas Pipe Size	GAS_PIPE_SIZE
HOT WATER	
Hot Water Capacity	HOT_WATER_CAPACITY
Hot Water Temperature	HOT_WATER_TEMPERATURE
STEAM	
Steam Pipe Pressure	STEAM_PIPE_PRESSURE
Steam Pipe Size	STEAM_PIPE_SIZE

[20] CBECS 2003 website, http://www.eia.gov/consumption/commercial/data/2003/#b1

Steam Process Pipe Pressure	STEAM_PROCESS_PIPE_PRESSURE
Steam Process Pipe Size	STEAM_PROCESS_PIPE_SIZE
VENTILATION	
Mechanically Ventilated Area	MECHANICALLY_VENTILATED_AREA
HEATING	
Heat Demand Unit	HEAT_DEMAND_UNIT
Heated Space Cubic Feet	HEATED_SPACE_CUBIC_FEET
Heating Capacity	HEATING_CAPACITY_MBTU
COOLING	
Air Conditioned Area Square Feet	AIR_CONDITIONED_AREA_SQUARE_FT
Air Conditioner Capacity	AIR_CONDITIONER_CAPACITY
Condensate Capacity	CONDENSATE_CAPACITY
Condensate Size	CONDENSATE_SIZE
Humidity Controlled Space	HUMIDITY_CONTROLLED_SPACE
METERS	
Meter Assignment Proration Percentage	METER_ASGMT_PRORATE_PCT
Meter Constant Number	METER_CONSTANT_NO
Meter Reading Count	METER_READ_COUNT
Meter Reading Date	METER_READ_DATE
Meter Reading Inoperative Indicator	METER_READ_INOPER_IND
Meter Rollover Amount	METER_ROLLOVER_AMT
MISCELLANEOUS	
Critical Utility	CRITICAL_UTILITY
Date Equipment Warranty	DATE_EQUIPMENT_WARRANTY

5.2.2 Improve Army benchmarks

The benchmarks established in this research were developed using the best information available at the time. Nevertheless, these benchmarking standards could be improved if steps are taken to increase the available datasets and/or further refine data collection and analysis techniques, as suggested below.

5.2.2.1 Benchmark more Army building types

The present study analyzed the energy consumption of Army building barracks, dining facilities, and vehicle maintenance buildings. To obtain a clear understanding of building energy consumption, however, many other

types of buildings also must be analyzed. EPAct 2005 requires the metering of all federal buildings where economically practicable.[21] This has been interpreted by the Army as all buildings larger than 29,000 ft^2 [22]. Among such large buildings, some are more common and critical than others and several are known to have particularly high EUIs. The buildings in Table 29 fall into this category and should be studied in accordance with their priority. They have been prioritized based on total floor area of the particular building type across all Army installations.

Table 29. Building priority for future benchmarking studies.

Priority	Total Floor Area (ft^2)	Quantity (Q3 FY15)	CATCODE	Description
1	61,749,142	619	61050	General Administrative Building (ADMIN GEN PURP)
	1,456,484	34	61001	General Administrative Building (MEPS)
2	15,521,513	249	21110	Aircraft Maintenance Hangar
	907,047	20	21114	Aircraft Maintenance Hangar (AC MAINT BAY)
3	15,947,268	44	51010	Hospital (MED CTR/HOSP)
4	13,429,900	165	73046	Dependent School
5	12,846,500	261	14185	Small Unit Headquarters Building (CO HQ)
6	11,628,508	144	17120	General Purpose Instruction Building
7	5,607,701	64	74053	Exchange Sales Facility (EXCH MAIN STORE)
8	5,199,001	67	74021	Commissary
9	4,568,022	54	14133	Operations Supply Building (SHIP/RECV FAC)
10	4,319,374	30	14162	Emergency Operations Center / SCIF

Additionally, the following buildings provide an excellent opportunity for future benchmarking studies owing to data collected in previous studies. By leveraging these data, more accurate benchmarking models could be generated. Army installation personnel could use these better understand the energy consumption of a greater variety of building types. Benchmarking models are recommended for the following building types:

- Army Reserve Center (ARC)
- Brigade Headquarters (BdeHQ)
- Battalion Headquarters (BnHQ)
- Child Development Center (CDC)
- Company Operations Facility (COF)
- General Instruction Building (GIB)
- General Purpose Warehouse (GPW)

[21] Public Law 109-58; DOE/EE-0312, p ii.

[22] Valine, Debra, "Corps of Engineers helps Army installations reduce energy use, save money", USACE Huntsville Center, August 31, 2009, http://www.army.mil/mobile/article/?p=26770.

- Information Systems Facility (InfoSys)
- Outpatient Healthcare Center (OHC)

5.2.2.2 Benchmark refinements

As more meters are added, larger datasets will enable more rigorous statistical analysis of Army EUIs, thereby improving benchmarking standards. As more installations and buildings are metered, development of installation-specific benchmarks that better reflect local missions and operations can begin.

Submetering is required to fully comply with the reporting requirements established in 10 C.F.R. § 433. Subsection 433 states:

> "Energy consumption for the purposes of calculating the 30 percent savings shall include space heating, space cooling, ventilation, service water heating, lighting and all other energy consuming systems normally specified as part of the building design except for receptacle and process loads."23

Only by submetering can process loads be eliminated from current building energy consumption figures as required by Subsection 433. Furthermore, submetering will increase the specificity and accuracy of benchmarking standards. For example, energy usage, such as that required for cooking in a DFAC, can be accounted for and removed from the overall energy consumption of the building. Since this load is ancillary to the energy requirements for the building, it is unnecessarily included in current energy consumption calculations. Ideally, building benchmarks would only account for building energy consumption independent of the activities within the building.

5.2.2.3 Weather normalization

As specified previously, this study did not normalize for weather-related changes in building energy consumption. Due to the logistical challenges of obtaining weather data at each location and a lack of 15 minute weather data at many locations, weather normalization proved to be infeasible. Nevertheless, the importance of such an analysis is not ignored. Currently,

[23] 10 C.F.R. § 433.1

the Illinois Smart Energy Design Assistance Center (SEDAC), in partnership with ERDC-CERL, is attempting to better characterize building energy use patterns. Studying the effect of weather conditions on building energy consumption is a significant step toward this goal. During this effort, for barracks in climate zone 4A, SEDAC is attempting to identify weather-dependent behaviors and nondependent behaviors; study nondependent behaviors; and identify facility components that drive such behaviors. Results are forthcoming.

5.2.3 Improve MDMS

Currently, MDMS data is highly dependent upon installation-specific reporting standards. As a result, some data are reported directly and accurately to MDMS while other data are manually uploaded in batches. This discrepancy can impact data quality and yield substandard or incomplete information. It is recommended that MDMS establish a means of verifying all uploaded data and that clear protocols be implemented for data recording, delivery, and analysis.

Clear building-type identification would also significantly improve the usability of the system. By identifying buildings using the DoD Real Property Categorization System (RPCS) category codes (CatCodes) in addition to their names, the system could be more easily organized, maintained, and queried.

Additionally, a column should be added to the MDMS database screen that states cumulative energy consumption. The system currently provides only interval data. Cumulative data would provide greater flexibility for data analysis. Separating the data into monthly and annual consumption figures would further increase the usability and practicality of the system.

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Appendix: Building Attributes Used in Data Analyses

Table A1. Analyzed data for barracks (possible outlier highlighted). [24]

Bldg ID	Climate Zone	Area (ft^2)	Construction Type	Construction Year	Data Year(s)	EUI ($kBtu/ft^2$)
B1	4A	40,640	Brick Veneer	1964	2013	100.28
B2	4A	40,990	Brick Veneer	1963	2013	113.51
B3	4A	40990	Brick Veneer	1961	2013-2014	117.97
B4	4A	40,990	Brick Veneer	1961	2014	109.80
B5	4A	40,640	Brick Veneer	1965	2014	105.10
B6	4A	40,640	Brick Veneer	1965	2014	80.02
B7	4A	40,640	Brick Veneer	1967	2014	167.90
B8	4A	40,749	Brick Veneer	1961	2014	110.50
B9	4A	40,749	Brick Veneer	1961	2014	123.41
B10	4A	40,749	Brick Veneer	1961	2014	128.43
B11	4A	40,749	Brick Veneer	1961	2014	123.75
B12	4A	43,718	Brick Veneer	1967	2014	93.92
B13	4A	43,718	Brick Veneer	1967	2014	153.33
B14	4A	43,718	Brick Veneer	1967	2014	181.88
B15	4A	43,718	Brick Veneer	1967	2014	182.30
B16	4A	55,448	Brick Veneer	2010	2014	147.19
B17	4A	55,448	Brick Veneer	2010	2014	117.45
B18	4A	55,448	Brick Veneer	2010	2014	135.40
B19	4A	55,448	Brick Veneer	2012	2014	105.11
B20	4A	55,448	Brick Veneer	2011	2014	98.32
B21	4A	55,448	Brick Veneer	2012	2014	77.79
B22	4A	55,448	Brick Veneer	2012	2014	70.85
B23	4A	43,718	Brick Veneer	1967	2014	219.25
B23	4C	105,852	Brick Veneer	1927	2014	34.80
B24	4C	50,768	Other	1957	2014	72.25
B25	4C	50,768	Other	1957	2014	65.64
B26	4C	107,225	Brick Veneer	1927	2013-2014	49.81
B27	5B	49,560	Concrete	2007	2014	75.41
B28	5B	95,858	Block	1998	2014	30.34
B29	5B	123,860	Block	2004	2014	80.95
B30	5B	123,860	Block	2004	2012	64.35
B31	5B	95,858	Brick Veneer	1998	2012	66.11
B32	5B	152,684	Combo: Wood/Masonry Frame	2009	2014	53.64
B33	5B	152,684	Combo: Wood/Masonry Frame	2009	2014	51.58
B34	5B	152,684	Combo: Wood/Masonry Frame	2009	2014	54.19
B35	5B	152,684	Prefab	2009	2014	58.29
B36	5B	152,684	Prefab	2009	2014	34.09

[24] Highlighted rows in Tables 25, 26, and 27 indicate potential outliers. Neither building proved to be an outlier after further analysis. See Section 4.4.

Table A2. Analyzed data for dining facilities (possible outlier highlighted). [25]

Bldg ID	Climate Zone	Area (ft^2)	Construction Type	Construction Year	Data Year(s)	EUI ($kBtu/ft^2$)
D1	4A	27,263	Brick Veneer	2012	2013-2014	456.30
D2	4A	20,580	Brick Veneer	1999	2013-2014	561.99
D3	4A	13,644	Brick Veneer	1966	2014-2015	332.72
D4	4A	13,280	Brick Veneer	1966	2014-2015	577.14
D5	4A	25,530	Brick Veneer	1967	2014-2015	341.34
D6	5B	26,500	Concrete	2011	2012-2013	245.20
D7	5B	26,500	Curtain Wall	2009	2012-2013	352.95
D8	5B	28,621	Block	2004	2014	391.56
D9	6A	13,939	Brick Veneer	2004	2013-2014	246.19

Table A3. Analyzed data for vehicle maintenance buildings (possible outlier highlighted). [26]

Bldg ID	Climate Zone	Area (ft^2)	Construction Type	Construction Year	Data Year(s)	EUI ($kBtu/ft^2$)
V1	2A	6,435	Unknown	1983	2013	126.40
V2	2A	15,466	Unknown	1983	2013	60.24
V3	2A	22,823	Unknown	1982	2013	32.55
V4	4C	14,617	Other	1942	2014	172.49
V5	4C	28,400	Other	1988	2014	130.44
V6	4C	37,147	Block	1959	2014	71.68
V7	4C	15,726	Other	1939	2014	165.12
V8	5B	37,039	Block	1993	2014	148.92
V9	5B	23,575	Block	1965	2014	88.46
V10	5B	27,175	Block	1966	2014	44.36
V11	5B	23,575	Block	1966	2012-2013	37.68
V12	5B	34,571	Concrete	2009	2014	69.97
V13	5B	34,571	Concrete	2009	2014	84.63
V14	5B	23,575	Block	1966	2014	34.65
V15	5B	23,575	Block	1966	2014	32.29
V16	5B	23,575	Block	1967	2014	25.27
V17	5B	23,575	Block	1967	2012-2013	34.78
V18	5B	34,571	Concrete	2009	2012-2013	67.09
V19	5B	16,386	Block	1995	2014	23.25
V20	5B	254,000	Block	1974	2014	54.23
V21	5B	45,200	Other	1983	2014	150.61
V22	5B	28,362	Other	1984	2014	144.75
V23	5B	34,128	Concrete	2010	2014	102.41
V24	5B	34,128	Concrete	2010	2014	127.66
V25	5B	27,949	Block	1987	2014	141.57

[25] Highlighted rows in Tables 25, 26, and 27 indicate potential outliers. Neither building proved to be an outlier after further analysis. See Section 4.4.

[26] Highlighted rows in Tables 25, 26, and 27 indicate potential outliers. Neither building proved to be an outlier after further analysis. See Section 4.4.

Abbreviations and Acronyms

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
AEWRS	Army Energy and Water Reporting System
ARC	Army Reserve Center
BdeHQ	Brigade Headquarters
BnHQ	Battalion Headquarters
BTU	British Thermal Unit
CatCodes	Category Codes
CBECS	Commercial Buildings Energy Consumption Survey
CDC	Child Development Center
CEC	California Energy Commission
CEHNC	U.S. Army Engineering and Support Center, Huntsville, Alabama
CERL	Construction Engineering Research Laboratory
CEUS	California Commercial End-Use Survey
COF	Company Operations Facility
CTS	Compliance Tracking System
DA	Department of the Army
DAIS	Data Analytics and Integration Support
DDOE	District Department of the Environment
DEIS	Defense Energy Information System
DFAC	Dining Facility
DGS	Department of General Services
DoD	Department of Defense
DoDI	Department of Defense Instruction
DOE	Department of Energy
DUERS	Defense Utility Energy Reporting System
EEIM	Enterprise Energy Information Management
EEM	Energy Efficiency Measure
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EO	Executive Order
EPA	Environment Protection Agency
EPAct	Energy Policy Act
ERDC	Engineer Research and Development Center

ESPC	Energy Savings Performance Contract
EUI	Energy Use Intensity
EXORD	Executive Order
FY	Fiscal Year
GFEBS	General Fund Enterprise Business System
GIB	General Instruction Building
GPW	General Purpose Warehouse
HPSB	High Performance Sustainable Building(s)
HQIIS	Headquarters Installation Information System
HVAC	Heating, Ventilating, and Air Conditioning
IECC	International Energy Conservation Code
I&E	Installations & Environment
IFS	Integrated Facilities System
InfoSys	Information Systems Facility
LINEST	Line Statistics
OHC	Outpatient Healthcare Center
OMB	Office of Management and Budget
MACOM	Major Army Command
MDMS	Meter Data Management System
MILCON	Military Construction
MOU	Memorandum of Understanding
MSC	Major Subordinate Command
NREL	National Renewable Energy Laboratory
PRIDE	Planning Resource Infrastructure Development and Evaluation System
RDTE	Research, Development, Test, and Evaluation
REMIS	Real Estate Management Information System
RFMIS	Rental Facility Management Information System
RPCS	Real Property Categorization System
RPIR	Real Property Inventory Reporting
SEDAC	Smart Energy Design Assistance Center
SEDS	States Energy Data System
TCO	Total Cost of Ownership
TEMF	Tactical Equipment Maintenance Facility
VBA	Visual Basic for Applications

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14. ABSTRACT

Current federal, Department of Defense (DoD), and Army energy-efficiency goals require a proactive approach to investment, building operations, and energy savings. Much responsibility for meeting these requirements is assigned to Army installation staff, who often have difficulties identifying and interpreting the applicable mandates. To address this problem, the research group began work to develop an intelligent framework that describes and clarifies interrelationships among energy efficiency, component maintenance and renewal, and mission requirements to support an integrated investment strategy that minimizes total cost of ownership (TCO). The main thrusts of the study were to develop integrated investment decision models, identify DoD facility Energy Use Intensity (EUI) benchmarks in a data-scarce environment, and analyze occupant-, system-, and component-level faults contributing to energy inefficiency.

A methodology for developing DoD-specific facility EUIs will serve as a decision framework for actions involving buildings with the highest EUIs. Thus, Army-specific benchmarking results will support more cost-effective component-renewal investment strategies. Altering the timing and grouping of investments can improve the energy efficiency to lower the TCO throughout the facility life cycle. This research will help the Army more effectively implement energy improvements to meet and exceed energy-efficiency requirements.

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